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Summary of Investigations 1982, Saskatchewan Geological Survey

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Saskatchewan
Energy and Mines

Summary of Investigations 1982, Saskatchewan Geological Survey

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FOREWORD

During 1982, the Saskatchewan Department of Energy and Mines was enacted by name change from the Saskatchewan Department of Mineral Resources. The new department also reflects an internal restructuring into a simpler format of four divisions: Executive Administration, Petroleum and Natural Gas, Energy, and Geology and Mines.

The divisions are subdivided into branches; and the Saskatchewan Geological Survey is that branch of Geology and Mines responsible for all geological projects in the department.

Nearly all geological projects currently underway are reported on in this year's Summary of Investigations. These are supplemented by related studies conducted, in conjunction with or independently of the Geological Survey, at the Universities of Saskatchewan, Regina and Windsor, Carleton University and the Saskatchewan Research Council.

In keeping with the trend of the past three years, the numbers and scope of field mapping projects, because of their higher logistics, have continued to shrink under the pressure of budgetary restrictions. Thus the action was taken to concentrate the major field program into the geologically complex Beaverlodge area. This program is essentially an investigative matrix of detailed mapping and economic geology involving four of the project leaders who, in the field, shared a common pool of summer assistants.

The Buffalo Narrows fuel peat resources utilization project is the sole survivor of the Canada-Saskatchewan cost-shared field projects. It is under the Conservation Renewables Agreement of 1981 and work is proceeding on schedule.

J. E. Christopher
Director

October 1982

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NOTE: Asterisked reports have an accompanying map. A list of accompanying map titles is placed on the inside cover of the map package.

PRECAMBRIAN MAPPING INVESTIGATIONS

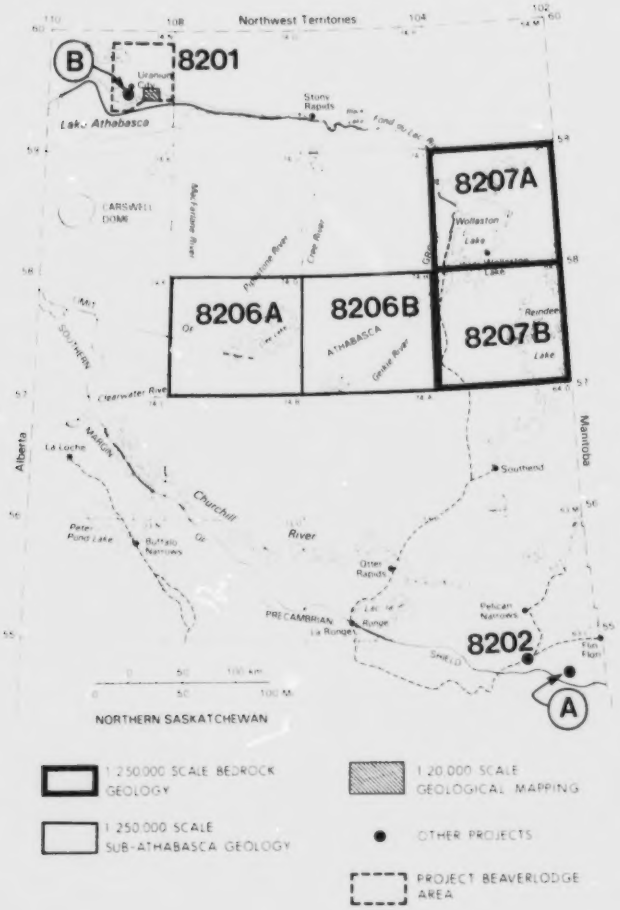

Figure 1 – Location of Precambrian bedrock mapping projects reported here. Numbers on map are official project numbers listed below.

Project No.	Area/ Short Title	NTS Sheet(s)	Project Leader(s)
Compilation Bedrock Geology, 1:250,000 Scale:			
8207A	Wollaston Lake Area	64L	M. Thomas
8207B	Reindeer Lake North Area	64E	M. Thomas and R. Macdonald
Sub-Athabasca Basement Geology, 1:250,000 Scale:			
8206A	Cree Lake Area	74G	C. F. Gilboy
8206B	Geikie River Area	74H	C. F. Gilboy
Geological Mapping, 1:20,000 Scale:			
8201	Hill Lake Area (UTM Sheet 6500-65900)	74N	R. Macdonald with M. Thomas
Other Projects:			
8208	Saskatchewan Shield Geochronology[1]	—	K. Bell
8202	Hanson Lake Geochemistry[1]	63L	J. W. Gaskarth
A	Geochemistry of Metavolcanic Rocks, Amisk Lake Area West[2]	63L	B. R. Watters
B	Gillies Channel Formation, Martin Group[2]	74N	C. G. Elliot

[1]Project contracted out.
[2]Project by another agency, which may have received logistic support from the department.

Introduction by Robert Macdonald

Without the funds necessary to continue with reconnaissance mapping activities, the main thrust of geological mapping in 1982 was the commencement of a new coordinated project known as Project Beaverlodge, a program which also involved members of the Economic Geology Section. The general objective of Project Beaverlodge is to review the work carried out in the "greater Beaverlodge area" (see Fig. 1 opposite) and to put together a regional geological synthesis as a means to promoting further mineral exploration, not only for uranium. The work is expected to involve detailed geological mapping of critical areas and compilation mapping of the geology, mineral deposits and other parameters.

Activities under Project Beaverlodge during 1982 included the production by Central Surveys and Mapping Agency (CSMA) of a series of 1:20,000 scale stereo-photomaps of the area, with funds contributed by the Saskatchewan Mining Development Corporation (SMDC) as well as the Saskatchewan Geological Survey. The new maps are based on 10 km square orthogonal grids of the UTM system and can be used directly in the field for insertion of data. Two map sheet areas were geologically mapped during the summer (see Macdonald with Thomas, and Sibbald, this volume). The geochronological project (see Bell and Blenkinsop, this volume) was devoted this summer entirely to sampling granites in the area. Other projects under the Beaverlodge program are indicated in the report.

The Sub-Athabasca Basement Geology Project (C.F. Gilboy) continued in the data-collecting phase. A start has been made into compilation with the production of two 1:250,000 subsurface basement maps (included with this report). A small contract was awarded to assist the University of Regina in a project to characterise the geochemistry of the volcanic rocks in the Hanson Lake area. The recently announced Granges/SMDC discovery of Zn/Cu mineralization in presumably similar volcanic rocks lying closely to the southwest under Phanerozoic cover is of interest in connection with this project. We have also included two reports by associated workers on the Martin Group and Amisk group (see Elliot, and Walker and Watters respectively, this volume).

Compilation Bedrock Geology: Wollaston Lake Area (NTS 64L)

by M. W. Thomas

The Wollaston Lake map area (NTS 64L) is situated within the Churchill Province of the Canadian Shield and exposes a variety of metamorphic and plutonic rocks affected by the Hudsonian orogeny (Stockwell, 1964; Douglas, 1980). Post-orogenic Athabasca Group terrigenous sandstones unconformably overlie the basement rocks along the western edge of the area (Ramaekers, 1980) and both the Athabasca Group and the basement are intruded by subvertical northwest-trending diabase dykes. Northerly trending lineaments and faults of undetermined displacement are common and form part of the Tabbernor fault zone which is traceable for at least 600 km in northern Saskatchewn (Macdonald, 1975, 1976; Macdonald and Broughton, 1980). A variable thickness of overburden consisting mainly of Pleistocene glacial deposits obscures the bedrock in many areas.

The rocks of the area have been grouped according to the general system of litho-structural domains established for the Sask-atchewan Precambrian Shield (Lewry and Sibbald, 1977, 1980; Macdonald and Broughton, 1980) and outcropping within the area are parts of the Mudjatik, Wollaston, Peter Lake and Rottenstone Domains. The geological legend on the accompanying map is in approximate stratigraphic order. However, relative ages and detailed stratigraphic relationships, especially within the pre-Athabasca basement, are not fully established in all cases. Absolute ages of some rock units are supported by limited radiometric dating both within and outside the map area.

In the compilation process, differences across borders of adjacent map sheets were eliminated by revising the original positions of geological contacts. These revisions were kept to a minimum. Also, the detail of original work had to be simplified in some cases in order to portray the geology at a 1:250,000 compilation scale. Other contacts not implied by the original workers have been inferred by the author from regional geological and aeromagnetic data. Previous in-house geological compilations of the Wollaston Lake map area by B.P. Scott and R. Macdonald are acknowledged.

Mudjatik and Wollaston Domains

Mudjatik Domain rocks underlie the northwestern part of the area and comprise granitoid gneisses and less abundant supracrustal gneisses. Recent workers have regarded the granitoid rocks to be mainly Archean basement material remobilized during Hudsonian orogenesis. The supracrustal gneisses are considered to be mainly Aphebian in age but may include Archean material as well. Spatially associated with the supracrustals are tonalite bodies probably derived from anatexis of the paragneisses. High grade regional metamorphism affected Mudjatik Domain rocks in the area, with upper amphibolite to granulite facies parageneses being preserved. Partial melting and migmatization of all rock types is common.

Structural trends of foliation and layering are non-linear and dips are generally steep to moderate but vary greatly over short distances. A basement/cover relationship between granitoids and supracrustal rocks has not been identified in the area; supracrustal belts are structurally conformable with the granitoid rocks and Ray (1978) has suggested that intense migmatization of Mudjatik Domain rocks was accompanied by structural inversion and repetition of units within the supracrustal belts.

Wollaston Domain rocks outcrop in the central portion of the area and comprise abundant supracrustal gneisses with subordinate foliated and unfoliated granitoids. As in the Mudjatik Domain, many of the granitoid bodies have been identified as remobilized Archean basement, but later discrete granitic plutons are present as well. The supracrustal gneisses are considered to be mainly part of the Wollaston Group (Ray, 1975) of probable early to middle Aphebian age. Within this group a broad regional stratigraphy has been recognized consisting of basal, commonly graphitic, pelitic to psammopelitic gneisses (Unit Wnps) overlain by predominantly arkosic calcareous and non-calcareous psammitic gneisses (Unit Wns, Wnsc). Local stratigraphic variations occur within this general sequence. For example, the distinctive Hidden Bay Assemblage (Units Wst, Wmq and Wq) exposed on Wollaston Lake and possibly in the Charcoal Lake area may be the uppermost part of the Wollaston Group (Lewry and Sibbald, 1980), or a lateral facies equivalent of the psammitic gneisses, Unit Wns (Ray, 1979). Unit Wn, considered by Ray (1979) to be equivalent to rocks of the Courtenay-Cairns Lake belt, appears to overlie the basal pelite/psammopelite on the flanks of

the Johnson River granite and may simply be a local facies variation in the Wollaston Group. Along strike to the southeast, however, the Courtenay-Cairns Lake belt in part contains the clearly distinguishable immature "lower meta-arkose unit" of Coombe, 1977 (equivalent to the Courtenay Lake group and the lower part of the Souter Lake group of Scott, 1970; included in the Needle Falls group of Ray, 1979). Similar immature rocks have not been identified in the Wollaston Lake map area. These Wollaston Domain rocks have undergone upper amphibolite facies regional metamorphism and, although variable in extent, anatexis and migmatization of supracrustal gneisses is common.

Structural trends of layering and foliation are predominantly linear in a northeast-southwest direction and dips range from subvertical to subhorizontal. Elongate, granitoid basement inliers occupy the cores of major doubly plunging, northeast- trending, upright antiforms and are mantled by the Wollaston Group supracrustal gneisses. Overturning of the supracrustal sequence does not appear to have occurred on a regional scale.

The junction between the Mudjatik and Wollaston Domains is not well understood in this map area. With some exceptions, equivalent rock assemblages are exposed in each domain but the two domains differ considerably in structural style. Ray (1978) has speculated that during the tectonic evolution of the area, Mudjatik Domain recumbent nappes or thrust sheets moved eastward on to the Wollaston Domain and that the resulting junction represents the edge of a series of nappes. Scarcity of outcrop and overprinting by subsequent deformation hampers verification of this hypothesis.

Peter Lake and Rottenstone Domains

Rocks of the Peter Lake and Rottenstone Domains are exposed in the southeast corner of the area and comprise a probable Archean basement intruded by megacrystic and non-megacrystic Hudsonian granitic rocks. The basement consists of strongly foliated granitoid rocks, volcanic-derived gneisses, and basic to intermediate plutonic rocks typical of the Peter Lake Complex south of the area (Ray and Wanless, 1980). Field relationships between these rock types are not well defined. The megacrystic granitoids intruding this basement are similar and may be equivalent to the Wathaman batholith of the Rottenstone Domain. Non-megacrystic granitoids intrude both the basement and the megacrystic rocks. This intermixing of Peter Lake-type and Rottenstone-type rock assemblages is in contrast to the situation south of the map area where the two domains are sharply defined and geographically separate, and is also in contrast to the situation east into Manitoba where granitoid rocks typical of the Rottenstone Domain (termed the Chipeywan Batholith in Manitoba; McRitchie, 1977) are extensively exposed and basic to intermediate plutonic rocks are totally lacking.

In general, structural trends in the Peter Lake and Rottenstone Domain rocks are slightly more easterly than those of the adjacent Wollaston Domain. However, in detail the structural and metamorphic history of these rocks is poorly understood. Hudsonian orogenic activity is mainly restricted either to felsic plutonism as represented by the megacrystic and non-megacrystic granitoids, or to discrete shear zones and mylonites.

The junction of the Peter Lake and Rottenstone Domains with the Wollaston Domain is also poorly defined in the area mainly because the Needle Falls Shear Zone, which delineates this boundary elsewhere to the southwest (Lewry and Sibbald, 1980; Ray and Wanless, 1980), is absent. Mylonites and shear zones which occur in the Peter Lake and Rottenstone Domains in this area are probably related to the Needle Falls Shear Zone but do not mark the boundary position (Ray, 1979). The domain junction is arbitrarily placed on the map between the most southeasterly occurrence of Wollaston Group-type supracrustal gneisses and the most northwesterly occurrence of Peter Lake Complex-type basic to intermediate plutonic rocks.

Economic Geology

Most recent exploration in the area has been for high-grade uranium concentrations related to the Athabasca Group basal unconformity and numerous major prospects and potential deposits of this type have been discovered (Can. Inst. Min. Metall., 1981). Uranium mineralization occurs (1) at the unconformity in saprolitic material; (2) directly beneath the unconformity in fractured, altered and commonly graphitic crystalline rocks; or (3) above the unconformity in bleached sandstone. A complex suite of other metals commonly accompanies the uranium mineralization; some of these can attain ore grade. Ages of initial mineralization range from about 1250 to 1000 Ma, generally coinciding with a period of diabase dyke intrusion (Hoeve and Sibbald, 1978).

The supracrustal gneisses of the Mudjatik and Wollaston Domains contain small occurrences of various metals including copper, zinc, lead,

uranium, molybdenum, silver and gold. Most of these are regarded as syngenetic accumulations with later concentration during Hudsonian mobilization and anatexis. None of these occurrences have proved economic to date.

Disseminated copper mineralization occurs in a layered basic intrusive 9 km east of Haglund Lake (Potter, 1979). MacQuarrie (1980) suggests that the Peter Lake and Rottenstone Domains may also contain volcanogenic sulphide mineralization and has pointed out that flourite-molybdenite occurrences in late granitic veins may indicate prospective granite related tin-tungsten-molybdenum mineralization associated with Rottenstone-type Hudsonian plutonism.

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Compilation Bedrock Geology: Reindeer Lake North Area (NTS 64E)

by M. W. Thomas and Robert Macdonald

The accompanying geological compilation map was essentially assembled by R. Macdonald in 1980. Detailing of the legend is mainly the work of M. Thomas in 1982. The legend is only partly arranged in broad stratigraphic succession and cannot be read as correlating horizontally. The following notes touch briefly on some of the problems encountered in drawing up this legend.

Apart from the unmetamorphosed Paleohelikian Athabasca Group outcropping in the extreme northwest and a small outlier of Athabasca-type conglomerates and sandstones at the south end of Reilly Lake, the area is mainly underlain by Precambrian rocks of Aphebian to late-Archean age. The broad stratigraphic sequence depicted in the legend for rocks of the Wollaston Domain is comparatively well documented, largely as a result of age determinations from the area immediately to the west and geological investigations throughout the Wollaston Domain. The Johnson River granite (c. 2515 Ma), which constitutes the largest mass of Unit Wfn, is overlain by early to middle Aphebian supracrustal rocks, predominantly assigned as the Wollaston Group. Unit Wrnv which underlies the Wollaston Group and comprises immature meta-arkoses and volcanogenic material, may belong to an earlier phase of deposition. This unit is equivalent to the "lower meta-arkose unit" of Coombe (1977) and to the Courtenay Lake and lower Souter Lake groups of Scott (1970); it forms part of Ray's (1979) earlier Aphebian Needle Falls group, indicated by Macdonald and Broughton (1980) as the "Courtenay-Sandfly" group.

Age relationships are less well documented in the Peter Lake Domain. Just west of the area, a late-Archean date was obtained from rocks resembling Unit Rb metagabbro-metadiorite of the Peter Lake Complex (Ray and Wanless, 1980). Although granites and granodiorites (Unit Rgl) included in the Peter Lake Complex may also contain Archean elements, they are generally regarded as Hudsonian in age. The Campbell River group, comprising mainly low grade, fine grained metasediments, is not conclusively dated but is apparently intruded by Unit Rb, thus suggesting an Archean age (Lewry et al., 1980). Zengle Lake-type quartzofeldspathic gneisses (Unit Rf) are also regarded as Archean because similar quartzofeldspathic rocks lying to the northeast are cut by Peter Lake Complex-type mafic plutonic rocks (MacQuarrie, 1980).

The distinction between rocks of the Peter Lake and Rottenstone Domains is very tenuous in the northeast; megacrystic granitoids (Unit Rgp) mapped as the Wathaman batholith further south become indistinguishable from megacrystic granitoids occurring in the Peter Lake Domain. The Wathaman batholith has been dated at approximately 1880 Ma (Bell and Macdonald, this volume). The Middle Lake granite (in part Unit Rgpx), which lies along the margins of the Peter Lake and Wollaston Domains, is probably a sheared equivalent; a Rb-Sr whole-rock isochron has produced an age of 1765±30 Ma (Bell and Macdonald, this volume).

Apart from the Wathaman batholith, no reliable date has yet been obtained from the Rottenstone Domain and age relationships in this mainly plutonic terrain are largely unknown. In general, the domain is considered to comprise paleosomes of Aphebian age (specifically in the Tonalite-Migmatite Complex) affected by Hudsonian metamorphism, anatexis and plutonism (Ray and Wanless, 1980).

The granitoid units Lgd and Lgtq which outcrop in the extreme southeast have been tentatively assigned to the La Ronge Domain because they seem to bear a closer resemblance to the northeast trending La Ronge Domain plutonic belt than to the Rottenstone Tonalite-Migmatite Complex (Johnston, 1979).

References

The following is a list of publications referred to in this report. Sources used in the compilation are given on the accompanying map. A complete bibliography for NTS 64E Reindeer Lake North is expected to be available shortly on open file of the Saskatchewan Geological Survey.

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Geology of the Hill Lake Area (NTS 74N, CSMA Photomap Sheet 6500-65900)

by Robert Macdonald, with M. W. Thomas and Norman Lee

The Hill Lake area is covered by one of the new UTM Stereo-Photomap sheets produced for the Project Beaverlodge program. The area was chosen for investigation because it appeared to bridge the transition from supracrustal rocks of the Murmac Bay group (Tremblay, 1972) eastwards to the more granitic gneisses lying east of Mackintosh Bay, and coincidentally because it covers the junction between the incompletely reconciled earlier 1:63,360-scale mapping of Christie (1953) and Blake (1955). The mapping included an attempt to determine i) whether any part of the more granitic gneisses represent granitized Murmac Bay rocks or their basement, and ii) whether any features of the regional geology can be related to known mineralization. This summer's mapping at 1:20,000 scale was completed in 42 traverse-days by Macdonald and Thomas. Data processing was handled by a Hewlett-Packard 9825 minicomputer employing a 9895A dual disc drive and 9874A digitizer, with map output through a SaskComp mainframe Calcomp plotter. The data file was designed by Macdonald working with Lee who wrote the computer programs. This computer mapping project is still in development with ultimate objective to input data at field location using battery-operated equipment.

In addition to the earlier reconnaissance mapping by Alcock (1936) and others, and Christie's and Blake's original mapping for the GSC, the area has been extensively explored mainly for gold and uranium since the early 1950's by company geologists and prospectors (Sakatchewan Energy and Mines assessment files).

The area is well exposed and is dominated by layered metamorphosed supracrustal rocks. Three well-defined foliated granitic bodies occur in the south. The regional attained metamorphic grade is at about upper amphibolite facies. Despite the high grade and local occurrence of intrafolial folds, the metamorphic layering and foliation are considered to be mainly mimetic of depositional origin.

The supracrustal rocks are folded regionally throughout the area on upright axial surfaces which plunge moderately to the southwest. A narrow 'straight belt' to faulted dislocation trends northeasterly along the eastern shore of MacKintosh Bay, offsetting lithological horizons in the north. In the south, opposite Davies Bay and Pedersen Island, the dislocation is marked by strong augen fabrics. A more profound separation also exists at this position as, to the northwest the supracrustal rocks are notably free of anatexis and depositional features are generally well preserved despite the high metamorphic grade, whereas to the southeast the rocks are generally more gneissic and anatectic. A few northerly-trending mineralized joint lineaments also occur.

Lithological Features

Over one hundred rock varieties were identified in the field. These have been provisionally grouped on the accompanying geological map and the reader is referred to the legend for details. The following interim account summarizes some of the main features.

The quartzites are extremely variable. More or less pure white to cream quartzite is persistent in two horizons along the main arm of Mackintosh Bay, but elsewhere feldspathic, ferruginous and calc-silicate-bearing types are interlayered with mica schists , siliceous metasediments and mafic rock. Consequently, mixed units have mainly been indicated on the map. Conglomeratic quartzite was rarely encountered. Quartz-sillimanite knots (faserkiesel) occur in many of the feldspathic varieties. Free carbonate rock is of restricted occurrence.

Immediately north and east of Taylor Lake the quartzite is interlayered with, and grades into siliceous metasediments and pink feldspathic gneiss. In this unit the quartzite occurs in thin interlaminations or ribbons varying from a few centimetres down to a fraction of a centimetre in thickness, a feature which probably derived from sedimentary layering, or possibly by mylonitization.

The rocks outcropping on the northeastern margin of the Mackintosh Bay granite around Dunbar Bay and Pederson Island are predominantly mixed dark quartzites and siliceous metasediments containing numerous finely laminated, variegated and massive amphibolite layers. Delicate sedimentary structures, including rare cross-bedding and possible soft-sediment deformational features, are typical in these 'epiclastic' rocks.

A belt of dark schistose rocks (Christie's 'mafic unit') lies between the two main quartzitic horizons north of Mackintosh Bay. These rocks are in places very fine grained and were not easy to identify in the field, but commonly contain noticeable biotite, garnet and hornblende. A distinctive dense rusty variety ('golfball rock') contains up to about 60 percent garnet in xenoblastic crystals up to 3 cm or more in size. Amphibolite, including pale schistose actinolitic amphibolite, and other mafic rocks are typically interlayered with the schistose rocks.

Several varieties of mafic rock have been mapped. Uniform fine- to coarse-grained massive amphibolite occurring impersistently east-west through Mackintosh Bay is probably volcanic flow material, as apparent pillow and interflow breccia features have been observed in several places along this horizon. The coarse material commonly contains large uniformly distributed megacrysts of what appear to be amphibole after pyroxene. The contact between the coarse and fine mafic rock varies from sharp to gradational, a feature which has been observed in greenstone rocks in the Flin Flon area (W.R. Gaskarth, pers. comm.) and observed by the author elsewhere.

Hackly amphibolites lying in the nose of the synform east of the Mackintosh Bay granite are vuggy in appearance due to the weathering out of carbonate. This horizon in places contains larger inclusions of carbonate up to a metre or so thick, but the carbonate is not persistent and no rock in the area was found which appears to qualify as a mappable carbonate unit (cf. Christie, 1953). Rocks lying adjacent to the hackly mafic unit immediately east of the northern end of Moose Island also contain carbonate and calc-silicate material, including rocks such as quartz breccia with a calc-silicate matrix, carbonate with large idioblastic garnet crystals, and coarse quartzitic conglomerate. In the same general area diopside occurs in quartzite in coarse crystalline masses up to 30 cm wide, commonly in association with tremolite.

A wide variety of laminated amphibolites occur. The mafic horizon associated with the pillowed massive rocks along the north shore of Mackintosh Bay contains a thick assemblage of finely laminated to fragmental amphibolites. The fragmental material is generally lensoid, rarely thicker than one centimetre, typically felsic and uniformly distributed, very suggestive of fragmental volcanic material. Some of the amphibolites are quite feldspathic.

Ultramafic rock, apart from that occurring in small restites, was found on the small promontory midway along the western side of Hill Lake, in association with coarse garnet schist. The weathering surface is typically white and serpentinized, contrasting strongly with the gossaniferous appearance of the garnet schist.

The area east and northeast of Mackintosh Bay is largely underlain by felsic and banded gneisses. Blake (1955) mapped these rocks as migmatites, granites and 'paragneisses'; the last-mentioned he regarded as being derived from greywacke or psammite. The writer, after examining the area in more detail, concludes provisionally that many of the gneisses in this part of the area derive from supracrustal rocks. Composition ranges from psammitic through psammopelitic, and includes quartzite, amphibolite and calc-silicate components. Some of these rock types appear to equate with the Murmac Bay units already briefly described in this report occurring west of Hill Lake. They differ only in being somewhat coarser grained, more definitely gneissose and in locally containing sweaty pegmatitic segregations. The pink felsic gneiss due north of Taylor Lake along the northern margin of the area is foliated and has a massive granitoid appearance, but its derivation is uncertain. The patch of felsic gneiss on the western border, south of Bearcat Lake, has both granitoid and strongly foliated features in different places. The pink felsic gneisses elsewhere, however, have a medium grain size and persistent foliation which is locally accompanied by regular and persistent layers and schlieren of biotitic and hornblendic material, suggesting derivation from an arkose.

Uniform blastic granitoid gneiss occurs largely around Hill Lake. Interlayered siliceous quartzofeldspathic gneisses and grey biotite-quartz-feldspar gneisses, both of which are regularly foliated and medium to fine grained, appear to have derived from siliceous metasediment (feldspathic quartzite) and psammopelite respectively. Quartz-sillimanite knots are fairly common. Garnet has been observed locally, particularly in some of the more quartzofeldspathic rocks. Calc-silicate pods also occur. Pelitic gneiss is rare in the area east of Mackintosh Bay.

The banded gneisses generally comprise well defined layers the order of one to several centimetres thick of alternating quartzofeldspathic and grey biotite gneisses. Amphibolitic, calc-silicate and actinolitic layers also occur in places. Pegmatitic sweats and semiconformable pegmatite are common locally but massive granitic injection is not prominent. These banded gneisses

probably correspond in part to the 'migmatite' mapped by Blake (1955).

The Mackintosh Bay granite and the granite exposed over Moose Island and neighbouring islands is typically a uniform pink, medium to coarse grained rock. Biotite, chloritized in places, is the main mafic constituent. The rock is generally foliated, in places with intersecting planar fabrics. Mineral rodding is usually present. Shear foliations and more discrete microshears are common, particularly around the margins of the granite and in association with inclusions of supracrustal material. Supracrustal rocks lie conformably with the contact of the granite on the southern margins, particularly in the strip of supracrustals lying between the main Mackintosh Bay granite and the Moose Island mass. On the northeastern margin, however, supracrustal rocks are clearly truncated by the granite, and the foliation trend of the supracrustals is continued across the contact into the granite. It may be provisionally concluded that the granite was emplaced before the expiry of the tectonism affecting the supracrustal rocks, and that the more discrete microshears represent late regional stress adjustments. The microshear zones are commonly concentrated along quartzite and other supracrustals, particularly on the southeastern margin of the granite.

Medium to fine grained mafic layers were fairly frequently encountered in the granite. Although many of these may represent relict supracrustal rafts, some at least are dykes. In one locality near the northern contact of the Moose Island granite, a mafic band contains biotite and is foliated, but is clearly seen to intrude the granite. Bodies such as these may represent an early dyke (possibly lamprophyric) phase.

The Cameron Island granite is generally coarser, and locally much coarser than the Mackintosh Bay granite. It is also generally a more intense pink and of more mafic composition, containing hornblende (locally chloritized) rather than biotite, and locally shows very strong shearing. Tourmaline may also be present, but has not been verified. Xenoliths and inclusions are less common compared to the MacKintosh Bay granite. Overall conformity is maintained with the surrounding supracrustal rocks. The regional southwesterly plunge is strongly reversed on the northern margin of the granite, forming the closed Hill Lake Synform, and it appears that this structure has been controlled by the position of the granite.

Two main types of pegmatite have been observed. Discrete cross-cutting pegmatites up to about a metre or more in width, which typically contain tourmaline, biotite, muscovite and/or garnet appear to be restricted to the area west of Hill Lake. Probable beryl was found in several discrete pegmatites on the extreme southeastern shore of Moose Island, and farther west outside the area (see Sibbald, this volume). Some of these cross-cutting pegmatites are weakly but congruently foliated along with the country rock, but others appear to be wholly post-tectonic.

Semiconformable pegmatites occur largely east of Hill Lake. Many of these range up to 15 m or more in width and can be traced for several hundred metres along strike. The grain size is variable, but is relatively fine in places, so that the granite resembles a coarse granite (some assessment file reports refer to these bodies as granite). Minerals include biotite and muscovite, but the colour index is low and the pegmatite is in places devoid of mafic minerals. Many of these pegmatites and the surrounding country rock show prominent uranium bloom. Partially processed data may suggest that these uranium pegmatites are stratigraphically controlled.

Post-tectonic lamprophyre and diabase dykes up to about 2 m wide have been recorded from a number of localities.

Gossan has been noted on the map in several localities. All gossans visited have been previously trenched. Trace copper mineralization was found in a thin north-south fracture in massive mafic rock on an island at the western end of MacKintosh Bay.

A number of exposures of granitic rock are spheroidally weathered. Supracrustal gneisses and granite on the northeastern side of the Cameron Island group are extensively kaolinized and weathered, and the granite shows spectacular spheroidal weathering. These features seem to indicate incomplete stripping by the glacial ice sheet and proximity either to an older land surface, or proximity to previous cover by the Athabasca Group. This may have implications for uranium unconformity mineralization. The discovery this summer in the Nicholson Bay area of a small outlier of Athabasca Group (Sibbald, this volume) is also of interest in this connection.

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Sub-Athabasca Basement Geology Project

by C.F. Gilboy

Since last year's progress report (Gilboy and MacDougall, 1981), work in both the field and the office has been concentrated on the southern half of the Athabasca Basin. Most assessment files relevant to this area submitted to the department by exploration companies have now been examined. During the past summer, 586 more drill holes from 21 different sites were logged for their sub-Athabasca basement section. Most of the 1232 drill cores so far studied have sampled sub-Athabasca rocks underlying the southeastern corner of the basin between Key Lake and Rabbit Lake, an area generally considered to have the highest potential for further discoveries of uranium ore.

Methods of Investigation

The main methods used to compile geological maps of the sub-Athabasca Group basement are direct observation of drill core and interpretation of various geophysical surveys.

Direct observation of drill core has been very rewarding, especially as most holes intersected at least 25 to 30 m of basement. Drill locations tend, however, to have been biased towards testing conductors, and accordingly have largely intersected graphitic metasediments.

The two most useful geophysical parameters employed in the regional interpretation of the sub-Athabasca basement are the conductive characteristics and magnetic patterns. Gravity surveys are locally helpful.

Linear and curvilinear EM conductors have generally been interpreted as graphitic pelites at or near the base of the Aphebian, close to the contact with felsic gneisses which probably represent Archean inliers. High magnetic relief, especially in the southeast of the Athabasca Basin, is typical of the relief found in supposedly Archean felsic gneisses lying south and east of the basin, and contrasts sharply with the low magnetic relief diagnostic of the Wollaston Group metasediments. This magnetic pattern is not found everywhere on the sub-Athabasca surface, however, because local enrichment of magnetite in the sediments produces magnetic relief similar to that of the felsic gneisses.

Geochemistry appears so far to be of limited value in the geological interpretation of the area, as extensive alteration has affected most core, and even material that appears fresh in hand-specimen is generally found upon thin section examination to contain sericitized plagioclase and chloritized biotite.

Geology

Preliminary 1:250,000 scale geological maps of the Geikie River (NTS 74H) and Cree Lake (NTS 74G) areas accompany this account.

In general, the geology of the sub-Athabasca basement in the Geikie River and Cree Lake areas resembles that of the surrounding exposed basement, both in rock types and in structural pattern.

The two rock types most commonly represented in sub-Athabasca basement core are semipelitic to pelitic biotite gneisses (Mp) and felsic gneisses (Fa-c). Other rock types have been intersected (see Table 1).

The felsic gneisses (Fa-c) are assumed to be mostly of Archean age. All three subunits distinguished below the southeastern part of the Athabasca Basin contain 5 to 10 percent biotite with or without minor amphibole.

Subunit Fa is comparatively homogeneous in both texture and composition and is dark to moderate pink, medium- to coarse-grained, and well foliated. Pegmatitic segregations make up about 10 percent of the rock, which also contains sporadic amphibolite bands 5 cm to 5 m thick. Where contacts with generally overlying metasediments have been intersected, the change from felsic gneisses into graphitic pelites is usually sharp and the gneissosity is conformable. Fa gneisses strongly resemble those of the Anderson Lake and Johnson River inliers to the south, which Ray (1978), and Ray and Wanless (1980) have interpreted as late Kenoran plutons.

The Fb and Fc gneisses are texturally and compositionally more variable than Fa gneisses, and possibly contain much material of supracrustal origin. Locally they are virtually indistinguishable from coarse-grained meta-arkoses or semipelitic biotite gneisses of probable Aphebian age. The difference between the Fb and Fc rocks is mainly one of colour: Fb gneisses are pale to moderate pink whereas Fc are pale grey to

Table 1. Basement rock types most commonly intersected by drill holes penetrating the Athabasca Group. Asterisked units are particularly abundant.

Derivation	Rock Type	Age or Orogenic Affinity
	Diabase (D)	Probably Helikian
Intrusive Rocks	*Pegmatite (P)	Probably Hudsonian and post-Hudsonian
	Granite (G)	
Metasedimentary Rocks (M, where undifferentiated)	Meta-arkose (Mm)	
	*Calc-silicate and marble (Mc)	
	Quartzite (Mq)	
	Biotite gneiss (semipelitic to pelitic) (Mp)	Probably Aphebian for the most part
	Biotite gneiss (graphitic, semipelitic to pelitic) (Mpg)	
Rocks of Unknown Origin	Amphibolitic gneiss (A)	Probably Hudsonian and pre-Hudsonian
	*Felsic gneiss (Fa-c, F where undifferentiated)	Probably Archean for the most part

white. The Fc gneisses also tend to be slightly more mafic and migmatitic than the other subunits.

Amphibolitic gneisses (Unit A) vary in grain-size from fine to coarse, in texture from highly schistose to almost massive, and in mafic mineral content usually from 35 to 70 percent. Biotite is usually present but is subordinate to amphibole. Although only rarely forming the only rock type in any one drill hole, they occur at all levels in the sub-Athabasca basement, and appear to be locally concentrated just above the contact with underlying felsic gneisses.

Pelitic to semipelitic graphitic biotite gneisses (Unit Mpg) are commonly interlayered with the non-graphitic biotite gneisses (Unit Mp). Wine-red garnets and dark greenish pyrite pseudomorphs of cordierite are abundantly preserved, as is fibrolitic sillimanite locally. Graphite is typically present in amounts varying from isolated scattered flakes to about 3 percent of the rock, but rarely forms intersections of up to about 30 percent several centimetres thick. Biotite gneisses are medium to dark grey and are mostly medium-grained well-foliated rocks.

Quartzites (Unit Mq) are common in the Geikie River map sheet area, especially in the general vicinity of Russell Lake. They are generally well foliated, white to pale grey, medium- to coarse-grained rocks in which kaolinized feldspar grains are numerous (up to about 5 percent of the quartzite). Muscovite flakes and sillimanite fibres are rare, and graphite is an accessory in only one or two places. Silica has been extensively remobilized so that the unit is locally massive in texture, and induration of the overlying Athabasca Group sandstones by silica is common. Several company geologists (pers. comm.) consider that the silica has hydrothermally replaced pre-existing pelites and semipelites. Whether the quartzite encountered in drill core represents one band or several is not known. Where drill hole fences have enabled rocks each side of the unit to be identified, the quartzite is found to be sandwiched between graphitic pelites and semipelites several tens of metres above the Archean-type felsic gneisses, and reaches a maximum true thicknesses in excess of 80 m.

Calc-silicates and marbles (Unit Mc), which have been rarely intersected in drill core, are interbanded with pelitic to psammitic gneisses. The calc-silicates are dark green, serpentine-rich rocks much cut by randomly oriented pale dolomitic veins a few millimetres to several centimetres thick. Marbles, either dolomitic or calcitic, are

fine- to coarse-grained and equigranular, and contain tremolitic amphibole, phlogopitic mica and/or brucite.

Meta-arkoses (Unit Mm) commonly underlie the Athabasca Group in an approximately 20 km-wide zone along the southeastern edge of the Athabasca Basin. Here, the rock is readily distinguishable from 'Archean-type' felsic gneisses, for generally it is much finer-grained, less well foliated, and contains only 1 to 2 per cent mafic minerals. Colour varies from pale or moderate shades of grey, to pale pink and pale green. The rock appears to coarsen towards the northwest, where meta-arkoses of probable Aphebian age

Table 2. Selected criteria used in identifying lithostructural domains in the Sub-Athabasca basement rocks.

Criteria	Western Craton	Virgin River Domain	Mudjatik Domain	Wollaston Domain
Magnetic relief	high	low	moderate	moderate
Magnetic patterns	essentially non-linear	essentially diffuse	essentially non-linear	essentially linear
Pelitic and semipelitic metasediments	generally much migmatized	generally little migmatized	generally much migmatized	generally little to moderately migmatized
	N/A	rarely cordierite bearing	commonly cordierite bearing	rarely cordierite-bearing, probable pyrite pseudomorphs after cordierite abundant
	N/A	generally lack accessory hercynite	commonly contain accessory hercynite	generally lack accessory hercynite
Metasediments in general	N/A	sporadic tourmaline	rare accessory tourmaline	accessory tourmaline
	contain quartz, commonly enclosing sillimanite needles	rarely contain quartz enclosing sillimanite needles	contain quartz commonly containing crystallographically oriented sillimanite needles	rarely contain quartz enclosing sillimanite needles
Amphibolitic gneisses	hypersthene common	hypersthene generally lacking	hypersthene common	hypersthene generally lacking
Felsic gneisses	hypersthene common	hypersthene generally lacking	hypersthene sporadic	hypersthene generally lacking
Quartz	commonly blue and extremely highly strained	generally grey and little strained	generally grey and highly strained	generally grey and moderately strained

are increasingly difficult to distinguish from Archean-type felsic gneisses.

Granites (Unit 9) seldom form complete sections of sub-Athabasca basement core, and no large Hudsonian or post-Hudsonian intrusions have yet been identified in this project. Granitic sills and dykes up to about 10 m thick are numerous, however. The rock in the sills and dykes is fine- or medium-grained, generally contains about 5 percent mafic minerals, is massive to weakly foliated, compositionally and texturally homogeneous, and mostly pink.

Pegmatites (Unit P) almost without exception form only segments of sub-Athabasca basement core. They have been emplaced as minor intrusions ranging in thickness from a few centimetres up to about 25 m, mostly in Aphebian metasediments. Grain-size varies greatly, from fine to extremely coarse. Most pegmatites are pink or white, and others are greenish-grey. The commonest accessory is biotite, but muscovite and/or tourmaline also occur. The last-named mineral is especially characteristic where pegmatites transect graphitic pelites and semipelites.

Diabase (Unit D) is rare in drill holes except in the Lazy Edward Bay to Diabase Peninsula vicinity (74G) and in the area adjacent to the inlier of Aphebian metasediments and diabase near Moore Lake, Geikie River area. The diabase is distinctively dark grey to dark green, medium- to coarse-grained, mostly equigranular and massive; subophitic textures are widely preserved.

Northeasterly extensions of four litho-structural domains - the Wollaston, Mudjatik, Virgin River and Western Craton - are traceable beneath the sediments of the Athabasca Basin, but without accurate demarcation. Some parts of the junctions between these domains appear to be gradational. Criteria used to identify these domains are listed in Table 2.

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Saskatchewan Shield Geochronology Project

by Keith Bell[1] and J. Blenkinsop[1]

Rb-Sr isochrons obtained during the fourth year of this project have further confirmed the timing of magmatic events outlined in a previous report (Blenkinsop and Bell, 1981) and have in addition, defined further the existence of another event in the Beaverlodge area at about 2180 Ma.

We have now analyzed a suite of samples from the Numabin tonalite, La Ronge Domain, that was not attempted previously because of a restricted spread in Rb/Sr ratios. The improved precision of our new Finnigan-MAT 261 mass spectrometer has enabled us to date the body and the value obtained, 1680±170 Ma, is not inconsistent with the 1740 Ma event found elsewhere in the Saskatchewan Shield (see Bell and Macdonald, this volume). It should be noted that the fairly high uncertainty associated with the age is a reflection of the limited spread in Rb/Sr ratios. The initial $^{87}Sr/^{86}Sr$ value of 0.7022±0.0002 is similar to values obtained from other granitoid bodies in the southeastern part of the Saskatchewan Shield.

Samples from the Box and Frontier granites in the Beaverlodge area have yielded an isochron with an age of 2155±40 Ma, and a high initial $^{87}Sr/^{86}Sr$ ratio of 0.729±0.007. The data from the two intrusions were combined because only two samples were available from the Frontier granite. The high initial ratio indicates that these granites were derived by partial melting of much older crustal material. So high an initial ratio has not been observed in any other granitoid rocks we have investigated in the Saskatchewan section of the Hudsonian orogen.

Samples from the Athona granite in the Beaverlodge area did not define a satisfactory isochron, but two samples with identical and high Rb/Sr ratios gave evidence of behaving as chemical systems closed with respect to exchange of Rb and Sr. We consequently calculated a model age for them by assuming an initial $^{87}Sr/^{86}Sr$ for the intrusion. The samples are highly enriched in radiogenic ^{87}Sr so the model age derived, roughly 2050 Ma, is fairly independent of the choice of initial ratio. Further work on additional samples is underway in order to confirm the model age.

We have extended our earlier study on the basement of the Carswall structure by analyzing two suites of pegmatoid rocks. The age of 1745±20 Ma for one suite is in agreement with that of the major pervasive Hudsonian event; the high initial $^{87}Sr/^{86}Sr$ of 0.717±0.001 suggests derivation of the rocks from older crustal material. The second suite yielded a similar age and initial ratio, albeit less precisely defined due to the restricted spread in Rb/Sr ratios for the samples.

Several suites of samples collected during the 1982 field season all from the Beaverlodge area, have already been analyzed for their Rb and Sr contents, and their Rb/Sr ratios. New suites include those from the MacIntosh Bay and Cameron Island granites, Beaverlodge area; a spread in Rb/Sr ratios sufficient for dating has been obtained in both cases. The Lodge Bay granite was also sampled and further material was obtained from the Box and Frontier granites. Additional samples from the Martin Formation volcanics and sediments also exhibit a suitable variation in Rb/Sr ratios.

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Operational costs of project provided by the Saskatchewan Geological Survey.

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Geochronological Calibration of the Precambrian Shield in Saskatchewan

by Keith Bell[1] and Robert Macdonald

This report summarizes the results of the Saskatchewan Shield Geochronological Program since its inception in 1976 and incorporates a review of other published geochronological data in the Precambrian Shield area of Saskatchewan. The Saskatchewan Shield Geochronological Program is a joint program of whole-rock Rb-Sr isochron determinations by Carleton University, Ottawa and the Saskatchewan Geological Survey, using operational funds provided by the Province of Saskatchewan. Many of the Rb-Sr results have not been published previously. Due to the broad scope of the article, rigorous systematic descriptions of the isotope methodology and systematics are not included. All ages quoted have been calculated, or recalculated, using the decay constants of Steiger and Jager (1977).

A regional geological framework became established for the central and southern parts of the Precambrian Shield in Saskatchewan largely as a result of the massive increase in geological mapping during the period 1974-80 (Lewry and Sibbald, 1977, 1980; Macdonald and Broughton, 1980) (Fig. 1).

The earlier Precambrian terrain has been divided into northeasterly-trending segments or domains, most of which are bounded by major faults or shear zones. The cratonic northwestern part of the Shield is essentially underlain by Archean rocks which are locally reworked and overlain by Aphebian (early Proterozoic) metasediments. A wide central part of the Shield, the Mudjatik Domain, is largely made up of pink felsic gneisses and granulites which form mobilized Archean dome cores to probable Aphebian supracrustals. In the Wollaston Domain, southeast of the Mudjatik Domain, more abundant Aphebian supracrustals are associated with basement dome cores elongated in the regional northeasterly trend. Farther southeast, across the Needle Falls Shear Zone, lie a sequence of linear domains or belts, including a major pluton (the Wathaman Batholith), and the La Ronge Domain which comprises higher level granites, greenstones and metasediments. The more complex southeastern and northwestern parts of the Shield are less well understood and contain elements of both Archean and Proterozoic rocks. Unmetamorphosed Helikian (Middle Proterozoic) sediments of the Athabasca Group blanket the central part of the Saskatchewan Shield.

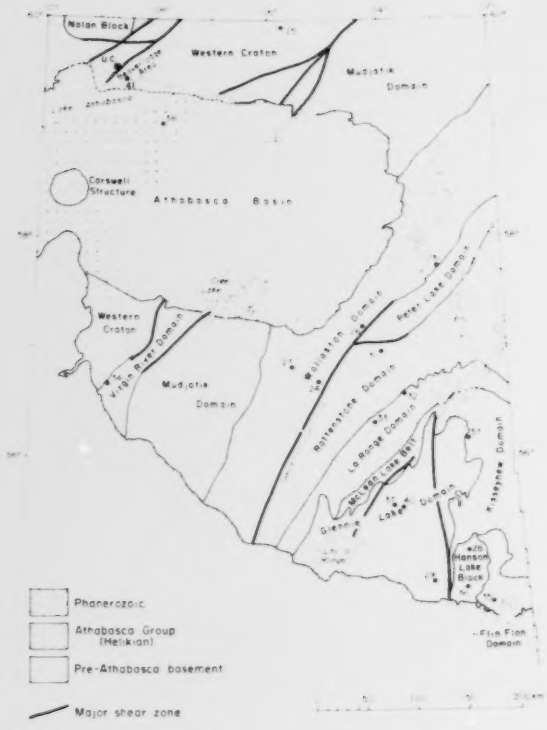

Figure 1—Tectonic subdivision of the Precambrian Shield of Saskatchewan (after Macdonald and Broughton, 1980, modified from Lewry and Sibbald, 1977) and locations of new whole rock Rb-Sr determinations outlined in this paper (see Table 1).

The only unequivocal Archean dates yet recognized in Saskatchewan are late Archean (c.2510 Ma) dates obtained by the U-Pb zircon method. These include dates from a dioritic tonalite from the Peter Lake Domain (Ray and Wanless, 1980), the Foot Bay gneiss from the Beaverlodge area in the northwest of the Shield (Tremblay et al., 1981), and the Johnson River granite, one of the Wollaston Domain domed basement inliers (Ray and Wanless, 1980). Groupings of whole rock Rb-Sr data points ("scatterchrons") from a number of basement domes in the Wollaston Domain, moreover, lie about a 2500 Ma reference isochron (Fig. 1, Table 1). The fairly large scatter of the Rb-Sr data is consistent with open-system behaviour possibly related to large-scale alkali metasomatism (Burwash et

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al., 1973), and to the post-Archean dome mobilization and metamorphism (Lewry and Sibbald, 1977).

Very late Archean or early Proterozoic ages have also been obtained from the Hanson Lake Block in the southeast of the Shield. A whole rock Rb-Sr date of 2410±40 Ma from the Sahli granite (Macdonald, 1976), a granulite facies pretectonic body infolded with supracrustal rocks, is similar to dates previously obtained from greenschist facies metavolcanic rocks and from a monzonite granite in the same block (Coleman, 1970). Although structural and metamorphic relations between the Hanson Lake Block and adjacent Aphebian (Kisseynew) gneiss terrain to the east are uncertain (Macdonald and MacQuarrie, 1978; Macquarrie, 1979; Sibbald, 1978; Clark, 1980), these dates confirm the existence of early Proterozoic or Archean material in this part of the Hudsonian Orogen.

Mineral K-Ar dates from a variety of metamorphic and non-metamorphic rock types in the Saskatchewan Shield (Lowdon, 1961; Lowdon et al., 1963; Wanless et al., 1965, 1966a, 1966b, 1968, 1970, 1974; Money, 1968; Koster and Baadsgaard, 1970) show two broad peaks when plotted on a conventional histogram (Fig. 2), one at about 2500-2300 Ma and the other at about 1890-1500 Ma. The older K-Ar dates are restricted to the Nolan Block in the extreme northwest (Fig. 1), a segment of granulite facies gneisses of mixed origin most of which show signs of retrograde metamorphism, and which appear to have escaped the pervasive effects of the Hudsonian Orogeny. Assuming that the retrograde metamorphism reset the argon systems to some degree, then the 2500-2300 Ma dates may indicate a retrogressive metamorphism with a minimum age of about 2500 Ma. A possible earlier (i.e. pre-Kenoran) event may be indicated by the original prograde metamorphism.

A restricted event at c.2180 Ma, first indicated by Baadsgaard and Godfrey (1967) in neighbouring Alberta and by Beck (1969) in the Beaverlodge area in the northwestern part of the Shield, has also recently become more conclusively substantiated by U-Pb zircon work (Donaldson Lake gneiss, c.2179±12 Ma, Tremblay et al., 1981) and by the new Rb-Sr isochron program. Combined data from the Box and Frontier granites yield a high initial $^{87}Sr/^{86}Sr$ ratio of 0.729±0.007 suggestive of partial melting of old crustal material, and an age of 2155±40 Ma, an isotopic signature not previously encountered in Saskatchewan.

In addition to these late Archean and transition Archean-Proterozoic dates, new whole rock Rb-Sr isochrons define distinct

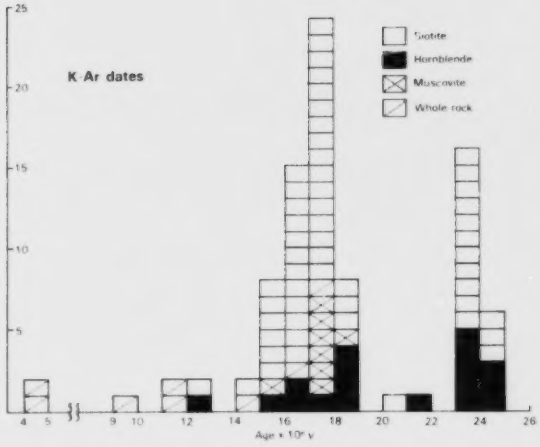

Figure 2—Histogram of previously published K-Ar dates from the Saskatchewan Shield (recalculated where necessary according to Steiger and Jager decay constants). For sources see reference list.

granitoid events at about 1880 and 1740 Ma, and a tentative third event at 1580±60 Ma (Table 1 and Fig. 3). The c.1880 Ma ("Wathaman") event is represented by a small and apparently late tectonic pluton in the southeast (the Deschambault granite at 1920±100 Ma) and principally by the Wathaman batholith (1895±45 Ma), a 400 km long body lying immediately southeast of the Mudjatik Domain (Ray and Wanless, 1980). A broadly synchronous metamorphic peak is probably indicated by a date of 1875±20 Ma from metasediments of the Wollaston Domain (Cumming and Scott, 1976). Granodiorite plutons in the Flin Flon Domain in the extreme southeast yield zircon dates at c.1875, c.1835, c.1810 and c.1800 Ma (MacQuarrie, pers. comm., 1980).

The c.1740 Ma ("younger granite" or "main" Hudsonian) event is well documented by several Rb-Sr whole rock isochrons from granitoid rocks spread widely throughout the Shield and from determinations in the Flin Flon Domain to the southeast (Mukherjee et al., 1971). Previously determined Rb-Sr dates (c.1760 Ma) from metamorphites in the Needle Falls area (Money, 1968), pegmatites in the Hanson Lake Block (Coleman, 1970) and lamprophyres elsewhere in the Shield (Sassano et al., 1974) yield similar dates in the range 1760-1740 Ma.

A metamorphic/anatectic event at c.1680-1655 Ma is suggested by two extremely short, although otherwise excellent isochrons from diorite gneiss and biotite granodiorite gneiss at Liz and Planinshek Lakes in the Glennie Lake Domain in the southeast; these samples have limited spreads in Rb-Sr ratios as well as low initial $^{87}Sr/^{86}Sr$ ratios of about 0.7018. Although overlapping slightly within limits of analytical uncertainty with the age

Table 1. Summary of whole rock Rb-Sr results to date in the Carleton University-Saskatchewan Geological Survey program

Reference Number	Rock unit/locality	Lat./Long.	Date obtained (Ma)[1]	$^{87}Sr/^{86}Sr$ Initial ratio	MSWD[2]
24	Anderson Lake granite	56 37N, 105 13W	Reference 2500 Ma isochron (scatterchron)		-
25	Granitoid pluton, Eynard Lake	59 57N, 105 45W			-
26	Johnson River granite	57 15N, 104 23W			-
27	Pederson Lake granite	56 45N, 105 39W			-
28	Sanli granite, Pelican Narrows	55 07N, 102 50W	2410±40	0.7056±0.0005	1.8
29	Deschambault granite	54 54N, 103 20W	1920±100	0.700±0.002	1.3
30	Wathaman granite	57 01N, 104 04W	1895±45	0.7024±0.0002	2.2
31	Middle Lake granite	57 45N, 103 03W	1765±30	0.7055±0.0014	2.7
32	Macoun Lake granite	56 35N, 103 45W	1740±45	0.7022±0.0001	4.2
33	Hickson Lake granite	56 16N, 104 23W	1730±30	0.7027±0.0001	2.5
34	Junction granite	56 40N, 108 45N	1720±45	0.7120±0.0028	1.7
35	Amisk volcanics, type-locality	54 42N, 102 26W	1665±90	0.7027±0.0004	1.9
36	Jan Lake granite	54 50N, 102 45W	(A) 1580±60 (B) 1750±20	0.7290±0.0110 0.7020±0.0004	2.0 1.5
37	Enderbite, Harriot Lake	56 12N, 102 43W	1525±80	0.7043±0.0017	1.4
38	Wolverine Point Formation Athabasca Group	59 06N, 107 47W	(A) 1470±30 (B) 1430±30	0.7105±0.0004 0.7188±0.0009	0.5 0.0
39	Quartz diorite gneiss, Liz-Dirks Lake area	55 35N, 103 55W	1655±70	0.7018±0.0001	0.3
40	Biotite granodiorite gneiss, Planinshek Lake	55 35N, 103 45W	1680±80	0.7019±0.0001	0.9
41	Box and Frontier granites	59 27N, 108 30W	2155±40	0.729±0.007	1.5

[1] Rounded to nearest 5 Ma
[2] Mean square of weighted deviates

of the "main" 1740 Ma event, these dates possibly indicate a separate and later event. As geological desciptions from the points of collection (Lewry, 1977) and from similar rocks in adjacent terrains (Padgham, 1966) indicate an anatectic supracrustal origin for the Liz Lake samples, a metamorphic anatectic age is suggested. The similarly dated Planinshek sample, only moderately foliated and of igneous origin (Lewry, pers. comm., 1981), may in fact be part of the same anatectic event or a broadly coeval plutonism. The strikingly similar dates from supracrustal rocks in the Thompson Belt of neighbouring Manitoba are also considered by Brooks to represent metamorphic events (Brooks and Thayer, 1981).

A 1580 Ma magmatic event, as yet only tentatively defined, may be indicated by the Rb-Sr data from the Jan Lake granite, a late or post-tectonic sheeted and dyked granitic to

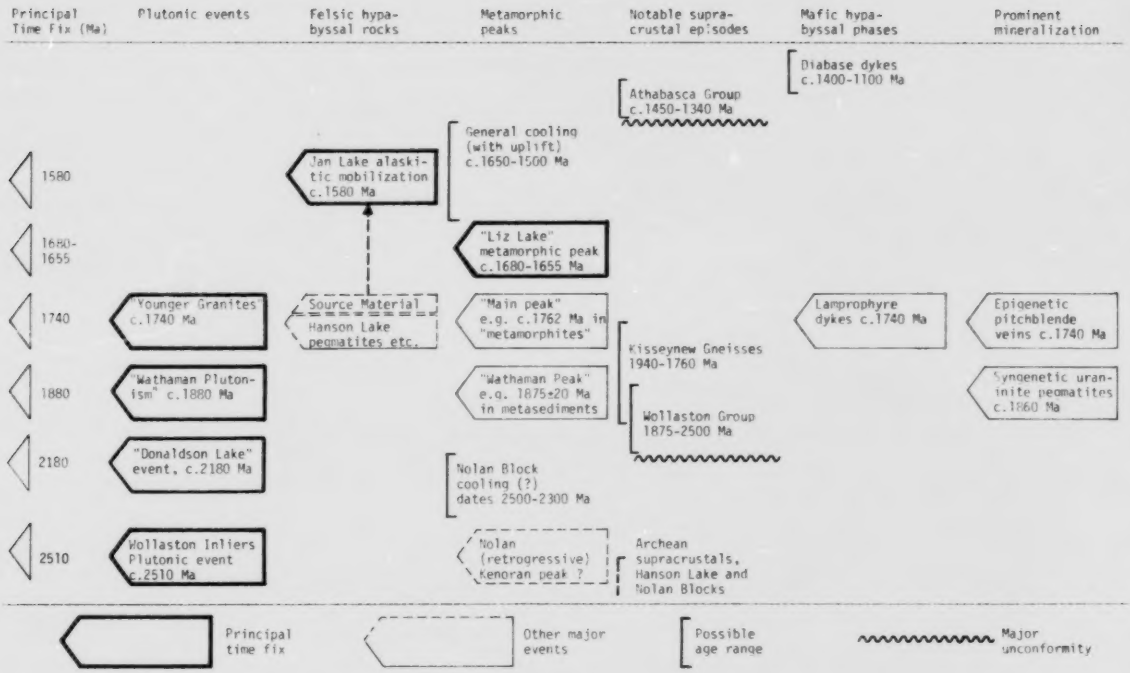

Figure 3—Schematic outline of the main known Precambrian geochronological events in Saskatchewan.

pegmatoid intrusion identified so far only in the Hanson Lake Block (Macdonald and MacQuarrie, 1978; MacQuarrie, 1979). Data from only those samples with the highest Rb/Sr ratios yield an isochron corresponding to an age of 1580±60 Ma and a very high initial $^{87}Sr/^{86}Sr$ ratio of approximately 0.729. However, other samples from the Jan Lake granite suite having $^{87}Rb/^{86}Sr$ ratios of up to 7.5 define an isochron with an older age of 1750±20 Ma and a lower initial ratio of about 0.702. The c.1750 Ma date may be an "ancestral" age related to the source material and the 1580 Ma date the age of mobilization (intrusion). Other interpretations are, of course, possible.

A whole rock Rb-Sr date of 1525±80 Ma has been obtained from enderbite sills in the Kisseynew Domain. Whole rock Rb-Sr determinations from lithologically and stratigraphically similar enderbitic rocks to the east in Manitoba, however, have given a date at c.1750 Ma (McRitchie, pers. comm., 1980). We find it difficult, based on the information available at present, not to interpret the younger (1525±80 Ma) date as an uplift or cooling age.

Some of the events identified by the Rb-Sr determinations undoubtedly reflect the K-Ar dates grouping between 1890 and 1500 Ma (Fig. 2). A comparison may be made with peaks of metamorphism recently postulated in the neighbouring Thompson Belt of Manitoba at around 1840, 1760 and 1600 Ma (Brooks and Thayer, 1981). Many of the Saskatchewan dates in this range, however, have a temporal spread and geographic pattern which appears rather to indicate uplift and cooling that was neither uniform nor synchronous across the Shield.

This interpretation of uplift and cooling fits in with what is known about the depositional age of the Athabasca Group sediments. Lying unconformably on a well-developed argillic regolith, the group is bracketted in age between the youngest K-Ar dates from the sub-Athabasca basement (c. 1550 Ma) and the emplacement of the Cree Lake and other diabase hypabyssals which cut the group 1400 to 1100 Ma ago (Sassano et al., 1974; Ramaekers, 1980; Wanless et al., 1973; Burwash et al., 1962). Whole rock Rb-Sr determinations of the Athabasca sediments have yielded three dates: 1340±50 Ma (Ramaekers and Dunn, 1977), c.1428 Ma (Ramaekers, pers. comm., 1980) and 1450±50 Ma, the latter from tuffaceous shales of the Wolverine Point Formation (revised from the previously published figure of c.1515 Ma (Macdonald and Broughton, 1980)). Deposition of the Athabasca Group sediments approximately 1450±50 Ma ago is compatible chronologically with their derivation from the eastern and southeastern part of the Shield following epeirogenic uplift.

The data emerging from the Saskatchewan Shield appear to be fitting in with age patterns emerging outside the Saskatchewan Shield (Camfield and Gough, 1977). Precambrian rocks exposed as inliers along the length of the North American Plains Magnetic Anomaly (Camfield and Gough, 1977), as for example in the Black Hills of South Dakota, have given uplift ages of 2500 Ma and 1700 Ma as well as some around 1500 Ma (Hills and Armstrong, 1974), in noticeable agreement with the ages currently presented from Saskatchewan.

The radiometric dates from the Saskatchewan Shield also reveal a sequence of metamorphic and magmatic events amongst which the 1740 Ma figure commonly attached to the Hudsonian Orogeny appears to mark only the peak of one event in a protracted cycle extending from the close of the Archean (c.2500 Ma) through to an epeirogenic regime at about 1500 Ma. This 'supercycle' includes a variety of pervasive and non-pervasive magmatic and metamorphic events, and a lengthy history of cooling and uplift.

Acknowledgements

J. Blenkinsop and T.J.S. Cole of Carleton University largely completed the isotopic work for the Rb-Sr program. Present and former geological staff of the Saskatchewan Geological Survey, including T.I.I. Sibbald, B.P. Scott, R.M. MacQuarrie, C.T. Harper, C.F. Gilboy, G.E.Ray, and W.G. Johnston, as well as J.F. Lewry, University of Regina, were involved in designing the geochronological program and in field collection, and some are expected to be reporting separately in detail on this work. L.S. Beck, J. Blenkinsop, T.I.I. Sibbald and C.F. Gilboy reviewed the manuscript.

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Hanson Lake Geochemical Project

by G. R. Parslow[1] and J. W. Gaskarth[2]

Initial geological mapping of the Hanson Lake Area was carried out by Byers (1957). More detailed mapping and geochemical work was carried out from 1962 to 1966 by Coleman, Gaskarth and Smith (1970), during which some 10,000 samples were collected. Gaskarth (1967), from selected major element analyses, interpreted the volcanics as calc-akaline in nature and considered them to be a western extension of the Amisk Series. However, more recent dating of these rocks as Archean (Coleman, 1970), and of the Amisk Series as Aphebian (Macdonald, 1981) may indicate that the two areas should exhibit different geochemical signatures.

The objective of this study is to characterize the Hanson Lake volcanics and compare them with the more easterly Flin Flon volcanics. If funds are available in future years, an attempt will be made to relate them to their more highly metamorphosed possible equivalents to the north.

During the summer, selected samples from designated traverses were taken from the Saskatchewan Geological Survey repository of samples collected by Coleman and Gaskarth over the field seasons 1962 to 1966. These selected samples (about 500) will be prepared and analysed for major and trace elements. Fig. 1 shows the traverses along which samples have been retrieved.

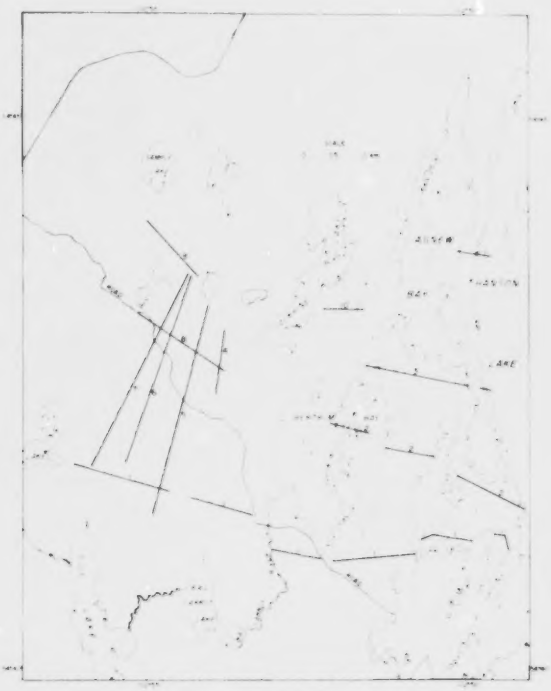

Figure 1 – Traverses along which samples will be retrieved, Hanson Lake area (based on Coleman et al., 1970).

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Geochemistry of Metavolcanic Rocks, Amisk Lake West Area

by D. Walker[1] and B.R. Watters[2]

The major and trace element geochemistry of Amisk group metavolcanic rocks, from an area on the west side of Amisk Lake (Fig. 1), has been examined in order to characterize the rocks and to interpret them in terms of their geotectonic environment of emplacement. Various workers have suggested that the Amisk group might represent an ancient island arc succession (Goodwin, 1969; Bailes, 1971; Stauffer et al., 1975; Lewry, 1981). The study area is included in geologic maps by Bruce (1918), Wright and Stockwell (1934), Byers and Dahlstrom (1954), Fox (1976b) and Macdonald (1981).

The Amisk group is an informally defined rock unit consisting generally of basic to acid

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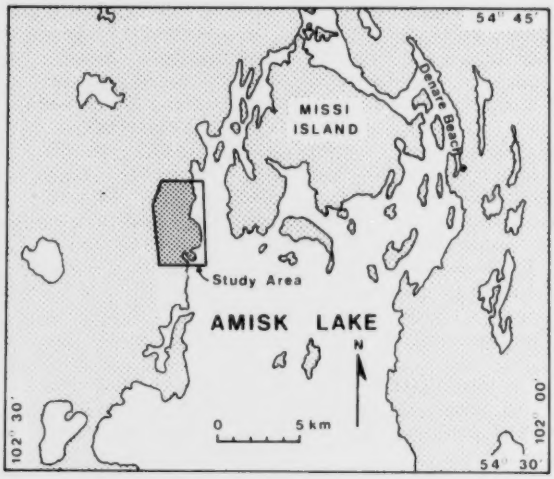

Figure 1—Location of the study area.

Table 1—Representative analyses of volcanic rocks from the Amisk Lake area. Major oxide values are in weight percent; trace elements in parts per million.

	1001	1006	1007	1014	1037	1041	1045	1125	1153	1161	1191	1206
SiO_2	60.5	57.2	48.5	65.3	70.9	57.8	63.5	62.9	68.6	56.2	64.4	60.4
TiO_2	0.76	0.68	0.98	0.50	0.40	0.83	0.44	0.84	0.26	0.56	0.51	0.75
Al_2O_3	15.8	15.9	18.1	16.0	15.3	19.0	15.8	14.9	14.7	16.1	15.0	14.6
Fe_2O_3	1.9	2.3	3.6	1.2	0.3	1.7	2.0	1.8	0.9	1.4	0.8	2.7
FeO	5.9	5.0	7.1	3.5	2.3	5.1	3.1	5.4	2.4	5.4	2.8	4.5
MnO	0.24	0.24	0.25	0.20	0.17	0.23	0.21	0.22	0.19	0.24	0.27	0.28
MgO	3.6	4.3	5.2	2.5	2.0	2.5	2.9	1.7	1.1	3.8	2.0	2.6
CaO	3.6	6.7	9.5	5.4	3.3	5.7	5.6	4.4	3.3	6.1	5.5	4.7
Na_2O	3.0	3.6	3.0	1.8	1.3	2.6	3.1	3.8	2.8	3.1	3.1	3.3
K_2O	1.8	0.62	1.1	1.0	1.7	1.7	1.6	1.1	2.0	2.3	1.1	1.1
P_2O_5	0.35	0.26	0.49	0.28	0.23	0.39	0.24	0.36	0.23	0.28	0.29	0.43
H_2O	0.04	0.20	0.04	0.12	0.14	0.0	0.0	0.0	0.04	0.16	0.05	0.73
loi	2.5	3.1	2.2	2.1	1.9	2.0	1.8	3.0	2.6	4.4	3.7	4.5
Total	100.0	100.1	100.1	99.9	100.0	99.6	100.3	100.4	99.1	100.0	99.5	100.1
Rb	30	6	27	22	20	27	23	12	26	30	14	8
Sr	357	351	401	240	129	337	317	260	149	221	287	164
Y	20	17	35	17	21	17	15	32	21	13	19	29
Zr	172	127	132	156	216	145	140	264	174	121	200	237
Nb	15	13	11	13	15	16	15	16	15	13	13	19
Ba	469	181	361	243	233	426	375	257	348	-	260	179
Rock Type	And.	And.	Bas.	Dac.	Rhy.	And.	Dac.	Dac.	Rhy.	And.	Dac.	And.

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volcanics, subvolcanic intrusives and volcanogenic epiclastics. A stratigraphic succession from basic tholeiitic to intermediate and acid calc-alkaline compositional character has been recognized (Fox, 1976a). Detailed physical volcanology and stratigraphic studies have been conducted in and adjacent to the study area by Ayres (1981a, b) and Ayres et al. (1981).

Dominant rock types of the Amisk group in the area are massive and auto-brecciated lava, laminated tuff, laharic and pyroclastic tuff-breccia, lapilli-tuff, and subvolcanic dikes and sills (Walker, 1982). All are metamorphosed, mainly to greenschist facies grade.

Major and trace element data were obtained for 45 samples of lava and tuff; representative analyses are presented in Table 1. Volatile content is regarded here to be an extraneous factor (due to modification mainly during metamorphism) causing variable dilution of the major oxides. Consequently, as suggested by Irvine and Baragar (1971), volatile-free oxide values have been employed in interpretation, and a few samples having volatile contents in excess of 5 percent have been rejected altogether from the data processing.

Major Element Geochemistry

In a suite of unaltered volcanic rocks, silica should exhibit good correlation with other major oxides and provide a valid index of differentiation in the intermediate to acid range (Cox et al., 1979). For the suite studied, a high degree of scatter is evident, with poor or no correlation of SiO_2 with Na_2O, K_2O, CaO, Al_2O_3, FeO and Fe_2O_3. Poor but distinct correlation exists between SiO_2 and TiO_2, MgO and FeO* (total iron as FeO) (Fig. 2). Positive correlation is also observed between FeO* and TiO_2 (Fig. 3) and MgO.

These results indicate that some movement of alkalis, calcium and alumina has occurred, probably as a function mainly of feldspar breakdown. Migration of alkalis is further suggested by the alkali igneous spectrum diagram of Hughes (1972), in which some of the metavolcanic rocks plot outside the field of unaltered igneous rocks (Fig. 4). This diagram helps detect samples affected by alteration or metasomatism involving both changes in total alkalis and in the sodium to potassium ratio, but distinction between the two effects cannot always be made. However, in this instance, the scattering of data points occurs mainly parallel to the x-axis, suggesting that the sodium to potassium

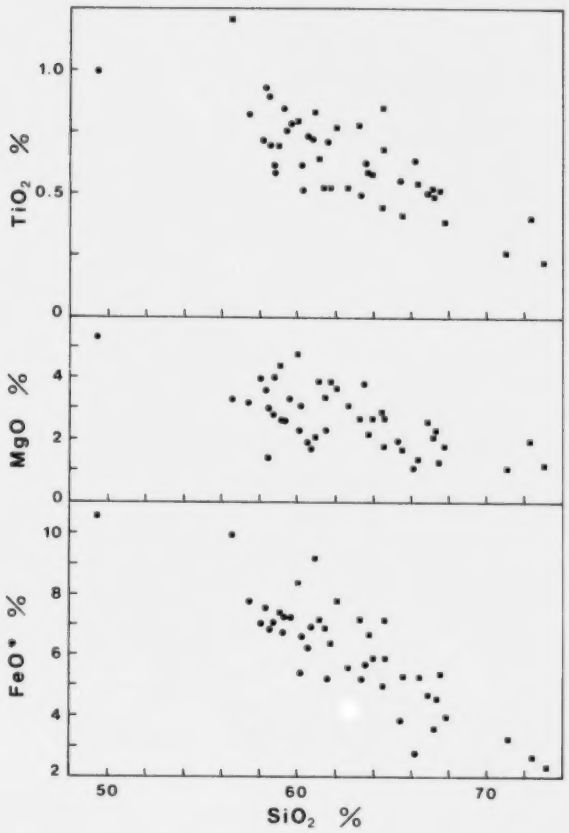

Figure 2—Harker-type variation diagrams for the Amisk Lake volcanics (dots, high-alumina group; squares, intermediate-alumina group).

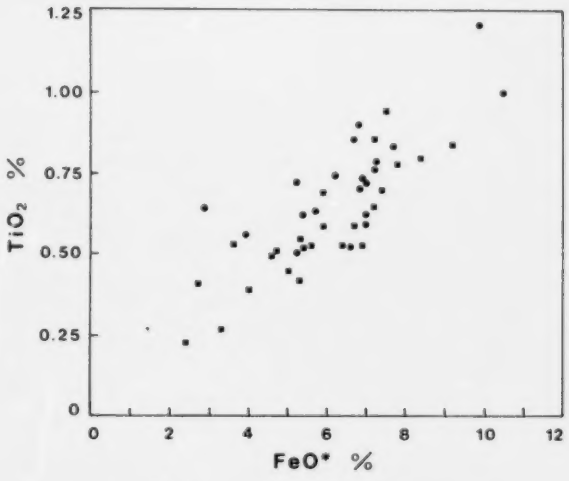

Figure 3—TiO_2 vs. FeO* (total iron as FeO) for the Amisk Lake volcanics using volatile-free values. Symbols as for Fig. 2.

ratios changed rather than the total alkali content. It is perhaps significant in this respect that samples with abnormally high K_2O generally have low Na_2O and vice versa.

Silica, total iron, magnesium and titanium appear to be relatively unaffected by metasomatism. The poor correlation between SiO_2 and FeO and Fe_2O_3 compared with that of FeO^* is attributed to variations in the oxidation state of the iron resulting from secondary processes. The variations have also resulted in a wide range of magnetic susceptibilities as indicated by field observations.

The metavolcanic suite has been divided into two groups based on their Al_2O_3 contents; a high-alumina group ($Al_2O_3 > 16.5$ percent) and an intermediate-alumina group ($Al_2O_3 \leq 16.5$ percent). Although the Al_2O_3 content used is arbitrary, differences in geochemical character between the two groups involving other major elements can readily be identified once this distinction is made. A plot of SiO_2 versus total alkalis (Fig. 5) clearly distinguishes the two groups: the high-alumina samples almost exclusively occupy the calc-alkaline (high alumina) field of Kuno (1966) whereas the intermediate-alumina samples fall into the tholeiitic field. The groups can also be recognized on the SiO_2 versus MgO and FeO^* variation diagrams (Fig. 2), where they define overlapping but different trends. For a given silica content, the high-alumina group is lower in MgO and FeO^*, and an improved correlation is displayed between SiO_2 and FeO^*, MgO and TiO_2 by each group as compared to the suite as a whole. In general, the high-alumina samples have lower SiO_2 contents and are predominantly andesitic; those belonging to the intermediate group have higher silica values.

Although the suite has been divided into two groups on the basis of differing major element characteristics, it is emphasized that these characteristics are transitional between the groups and, in many instances, overlap to varying degrees. This continuum suggests a close genetic relationship between the two groups. The intermediate-alumina group may have been derived by plagioclase fractionation of the high-alumina group magma, and may also be transitional between the high-alumina group and the basic tholeiitic volcanics which occur elsewhere in the Amisk Lake area (Fox, 1976a, b).

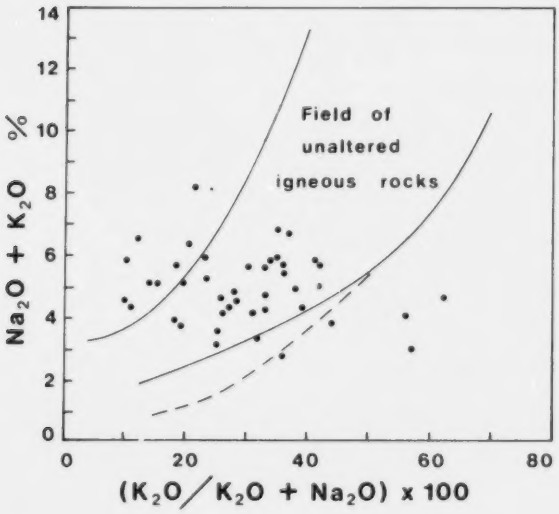

Figure 4—Alkali igneous spectrum diagram of Hughes (1972) for the Amisk Lake volcanics. Field of unaltered igneous rocks has been extended by the dashed line to include island arc tholeiites (after Stauffer et al., 1975).

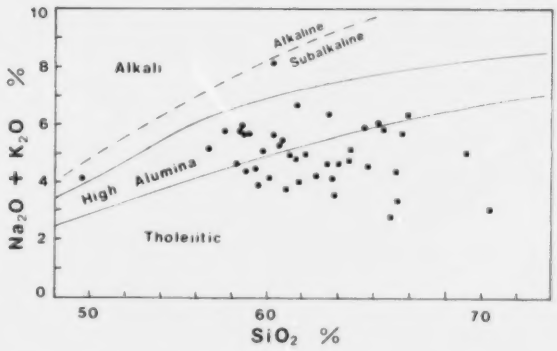

Figure 5—Plot of total alkalis vs. silica for the Amisk Lake volcanics. Boundaries separating the alkali, high-alumina (calc-alkaline) and tholeiitic fields are from Kuno (1966); the boundary separating the alkaline and subalkaline fields is from Irvine and Baragar (1971). Symbols as for Fig. 2.

Classification by Major Elements

The distribution of silica values (Fig. 6) indicates the presence of approximately equal amounts of andesite and dacite, with minor basalt and rhyolite.

According to the classification of volcanic rocks by Irvine and Baragar (1971), the suite studied represents an intermediate calc-alkaline sequence. This classification utilizes normative parameters which are sensitive to metasomatism (Church, 1975) and its application to the volcanic rocks of the Amisk Lake area may be of questionable validity. However, interpretation of the suite as having intermediate calc-alkaline affinities is supported by the compositional relationships between less mobile elements such as Si, Fe, Mg and Ti.

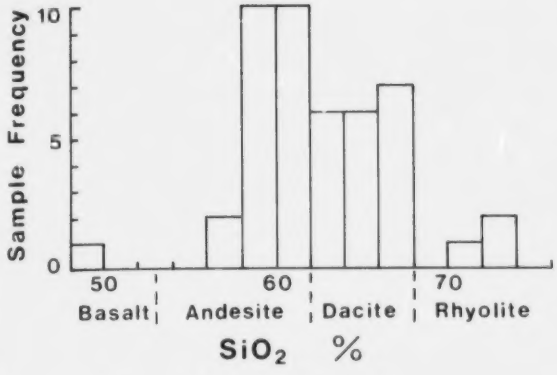

Figure 6—Distribution of SiO_2 in the Amisk Lake volcanics ($\bar{x}$ # 62.6 percent, N # 45).

The Irvine and Baragar (1971) scheme uses an AFM plot to distinguish between calc-alkaline and tholeiitic suites. The Amisk Lake suite clearly defines a trend in the calc-alkaline field on this diagram. The compositional trend also coincides with similar trends, of low iron enrichment, displayed by typical Recent calc-alkaline suites (Fig. 7). However, because of the possibility of alkali migration, classification using this diagram may also be questionable, although, as discussed earlier, alkali mobility probably resulted in changes in sodium to potassium ratios rather than in total alkali contents.

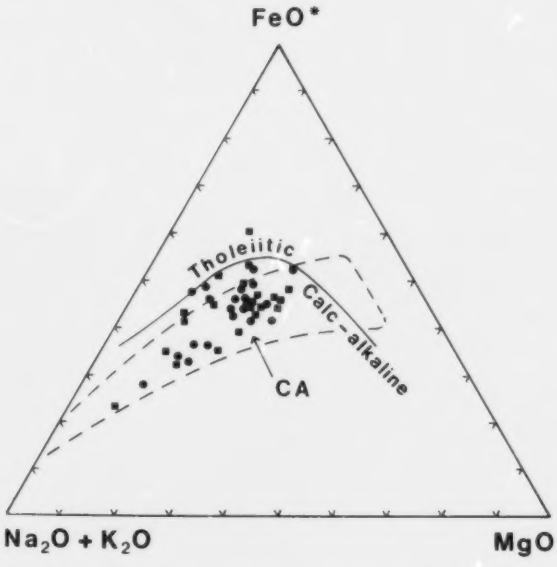

Figure 7—AFM diagram showing the compositional trend displayed by the Amisk Lake volcanics compared with differentiation trends of typical calc-alkaline volcanic suites (band CA # Cascade, Aleutian and New Zealand provinces) after Ringwood (1975). The calc-alkaline/tholeiitic boundary (solid line) is from Irvine and Baragar (1971). Symbols as for Fig. 2.

An 'SFM' ternary diagram ($SiO_2/10$ - FeO* - MgO) has been devised for this study, allowing a distinction to be made between calc-alkaline and tholeiitic suites (Walker, 1982). Silica has been used in this diagram because of its apparent relative immobility compared to the alkalis in the Amisk Lake suite. Field boundaries were established on this plot from several Recent volcanic suites of known geochemical affinity. The suite studied defines a trend plotting almost exclusively in the calc-alkaline field (Fig. 8).

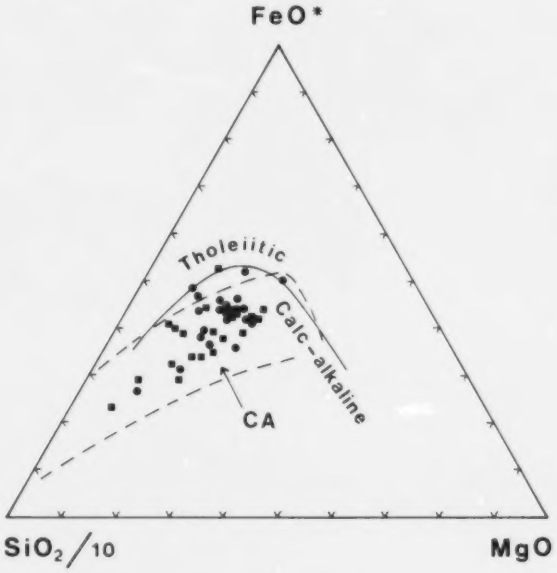

Figure 8—SFM diagram showing the compositional trend displayed by the Amisk Lake volcanics compared with differentiation trends of typical calc-alkaline volcanic suites (band CA # Cascade province, Fuji, Lesser Antilles). Symbols as for Fig. 2.

Although the majority of samples belonging to the intermediate-alumina group fall into the tholeiitic field (after Kuno, 1966) of the alkali versus silica plot (Fig. 5), they are not considered to be true tholeiites. The more rigorous classification of Irvine and Baragar (1971) identifies these rocks as calc-alkaline. Evidence of a tholeiitic trend of iron enrichment on the AFM and SFM plots is lacking. As mentioned earlier, this group may represent a transitional series.

The application of both the AFM and SFM diagrams to determine the character of a volcanic suite requires that it be subalkaline. Figure 5 indicates that the Amisk Lake suite is indeed subalkaline and although the alkalis seem to have been mobile

it is considered unlikely that the total contents of these elements have been significantly modified. The subalkaline nature of the suite is further demonstrated by low TiO_2 values.

Classification by Trace Elements

Trace element data generally support the interpretation of the Amisk Lake suite deduced from major element data.

A plot of Zr/TiO_2 versus SiO_2 (Winchester and Floyd, 1977) classifies the suite as a subalkaline intermediate sequence (Fig. 9). The elements Zr and Ti are considered to be relatively immobile and the ratio Zr/TiO_2 serves in this case as an indicator of alkalinity.

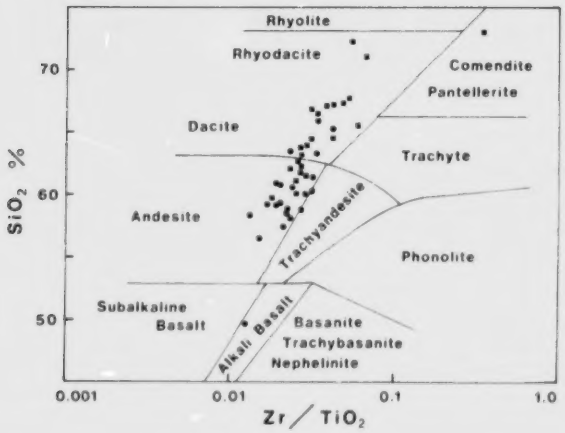

Figure 9—Plot of Zr/TiO_2 vs. SiO_2 (volatile-free values) for the Amisk Lake volcanics. Classification boundaries after Winchester and Floyd (1977). Symbols as for Fig. 2.

Davies et al. (1979) used a ternary plot [(Y + Zr)-TiO_2-Cr] to distinguish between calc-alkaline and tholeiitic suites in altered Archean volcanics. Chromium values are available for only six samples from the study area and these plot along a narrow band on this diagram with SiO_2 increasing toward the (Y + Zr) apex (Fig. 10). This trend conforms to that shown by Davies et al. (1979) for calc-alkaline suites.

Concentrations of the trace elements Sr, Rb, Y and Ba are consistent with those suggested by Jakes and White (1972) as being typical of Recent calc-alkaline suites from island arcs. Comparisons of average concentrations (in ppm) for the Amisk Lake rocks with averages (bracketted) from Jakes and White (1972) are:

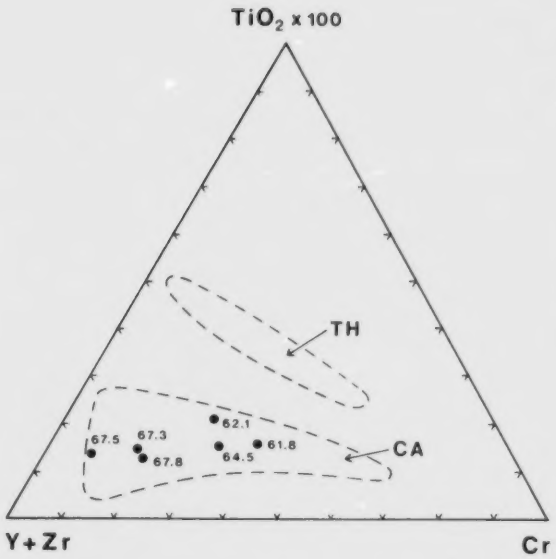

Figure 10—Plot of (Y + Zr)—TiO_2—Cr for six samples from the Amisk Lake area. Numbers refer to the SiO_2 value (volatile-free) for each sample. Bands CA and TH represent trends of Archean calc-alkaline and tholeiitic suites (after Davies et al., 1979).

	Sr	Rb	Y	Ba
Andesites	348(385)	21(30)	23(21)	326(270)
Dacites	310(460)	26(45)	22(20)	426(520)

Interpretation of Geotectonic Environment of Emplacement

Cenozoic calc-alkaline intermediate volcanism is considered to be characteristic of, and confined to, subduction-related geotectonic settings (Ringwood, 1975). By analogy, we believe that the volcanic rocks of the Amisk Lake area developed along a convergent plate margin active during late-Aphebian times. The common occurrence of turbidites and pillowed lavas, and the absence of voluminous masses of felsic ash-flow tuff, are suggestive of an island arc environment rather than of a continental margin magmatic arc.

A continuous transition from basic tholeiitic to intermediate calc-alkaline volcanism is a characteristic of the evolution of Recent island arcs (Ringwood, 1975) and, therefore, the occurrence of large volumes of probable arc-type extensively pillowed tholeiitic basalt in the Amisk Lake and Flin Flon areas (Mukherjee, 1971; Fox 1976b; Stauffer et al., 1975; Parslow and Watters, 1980) is regarded as highly significant. The calc-alkaline suite studied here possibly represents the later, upper and more emergent parts of an

island arc, whereas the pillowed tholeiitic basalts may represent an earlier, predominantly subaqueous phase.

Conclusions

1. Major element geochemistry indicates that the volcanic rock types studied from the Amisk Lake area are intermediate calc-alkaline in character and are dominantly andesite and dacite with minor basalt and rhyolite.

2. The suite can be divided into two transitional groups: a high-alumina group (Al_2O_3 > 16.5 percent) and an intermediate-alumina group ($Al_2O_3 \leq$ 16.5 percent). The former group is characterized by generally higher alkalis and lower MgO, FeO* and SiO_2.

3. Trace element data generally support the interpretations based on major element data.

4. Migration of alkalis and calcium is considered to have occurred within the volcanics. The alkali mobility appears to have affected the Na to K ratios rather than the total alkali contents. Other elements have apparently remained relatively immobile.

5. The volcanic suite is regarded as having evolved as part of an island arc succession.

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A Description of the Gillies Channel Formation, Martin Group

by Colleen G. Elliot[1]

The Gillies Channel Formation is part of the Martin Group of the Beaverlodge area (Langford, 1981). The Martin Group is a red-bed sequence of feldspathic sandstones, conglomerates and siltstones. In the Gillies Channel Formation a series of mafic flows interbedded with sandstones outcrop in a semicircle around the west, east and south sides of Martin Lake. The formation was studied in order to determine its sedimentology and stratigraphy.

The area studied (Figs. 1 and 2) extends for 3 km south of Padget Bay on Beaverlodge Lake and includes the peninsula east of Padget Bay. Outcrop is abundant but not continuous in the area, and excellent exposures are found at the Martin Lake Mine, Pitch ore and Martin Lake adits, and on the walls of steep ridges and cliffs.

General Geology

The Gillies Channel Formation is exposed on the flanks of the northeasterly-plunging syncline that forms the Martin Basin. Though the formation has been folded and is cut by numerous small radial faults, the rocks have no penetrative deformation and are unmetamorphosed. The unit is composed of a 1500 to 3000 m thickness of predominantly pink, red and purple conglomerates and feldspathic sandstones, interlayered near the top with mafic flows.

Whole-rock K-Ar dating by Fraser et al. (1970) produced an age date of 1635±180 Ma for the Gillies Channel volcanics. Evans and Bingham (1973), using paleomagnetic methods, postulated a paleolatitude of 16°, and an age between 1835 and 1720 Ma for the deposition of the Martin sediments. This places the group within the late Aphebian or early Helikian era.

For descriptive purposes, the Gillies Channel Formation is treated here as comprising three units: the basal conglomerate, the central sandstone, and the upper sandstone and volcanics (Figs. 3 and 4).

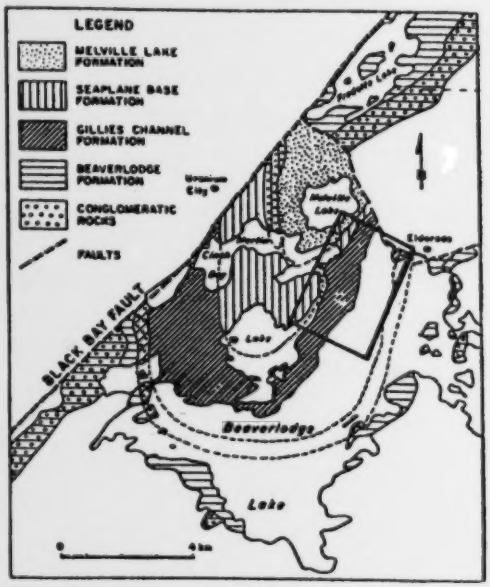

Figure 1—Geological map of the Martin Basin (Langford, 1981). Location of study area (Fig. 2) is outlined.

Basal Conglomerate

The basal conglomerate is exposed on the small penninsula east of Padget Bay as indicated on Tremblay's (1972) map. The 500 to 600 m thick section of conglomerate has subrounded and rounded cobbles up to 50 cm across of quartz, granite, amphibolite and gneiss. The conglomerate is unsorted, unstructured and varies locally from clast to matrix supported. Scattered beds up to 1 m thick of salmon pink to purple pebbly sandstone, which are difficult to trace, occur in outcrops along the road (outcrop 80). The rocks vary in colour from yellow to buff, brown, red and purple on weathered surfaces, and dark purple to pink, buff and green on fresh surfaces.

The matrix of the conglomerate is generally red or purple sandstone with up to 60 percent feldspars. Grains are angular to subrounded and are up to 3 mm in size. The grains are cemented by earthy hematite, quartz and greenish-grey clay, though in some places cement is absent. At outcrop 79 near the east corner of the map area, the rock has a

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[1]University of Saskatchewan. This project was supported logistically by the Saskatchewan Geological Survey.

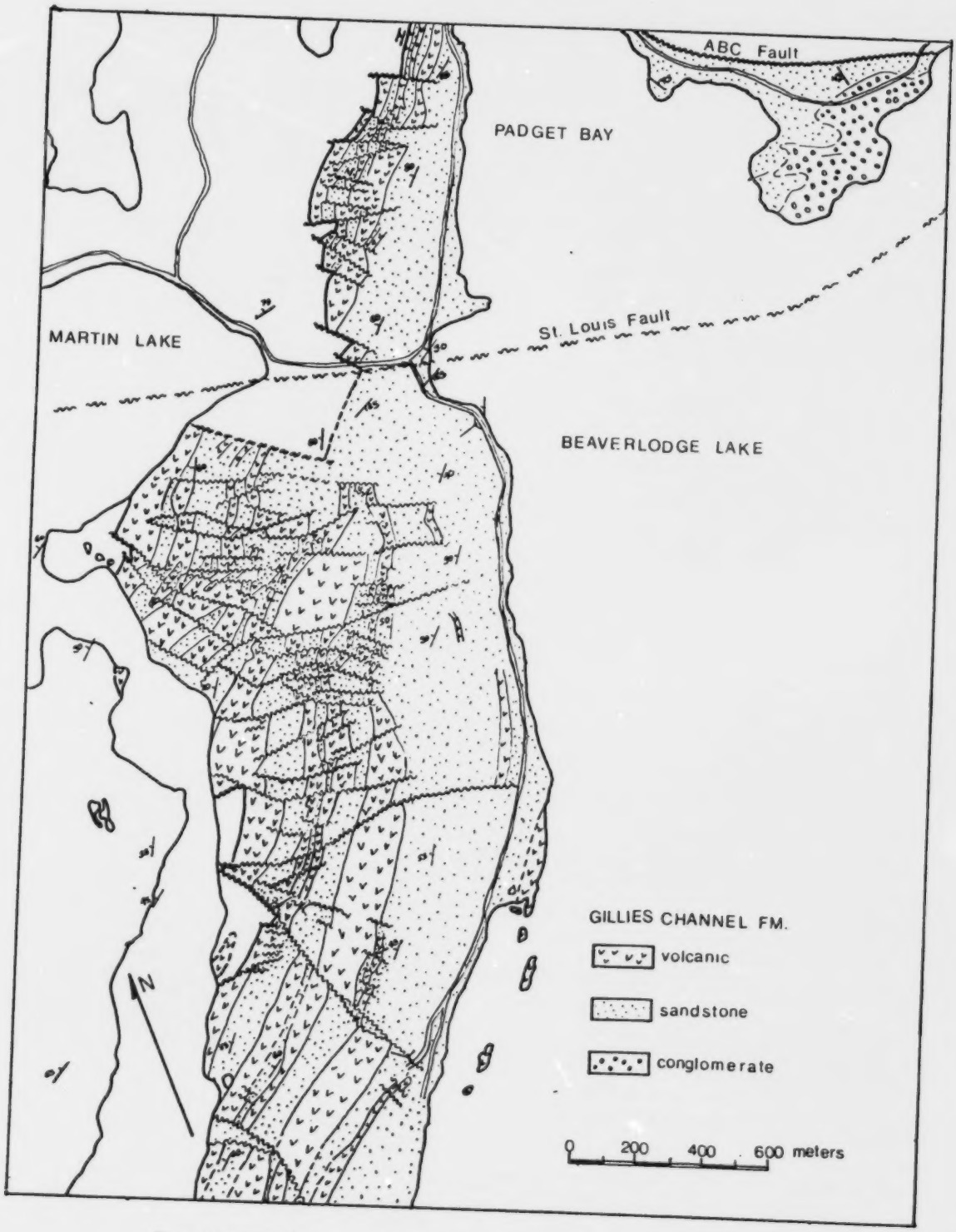

Figure 2—Geology of the Gillies Channel Formation south of Padget Bay (Tremblay, 1972).

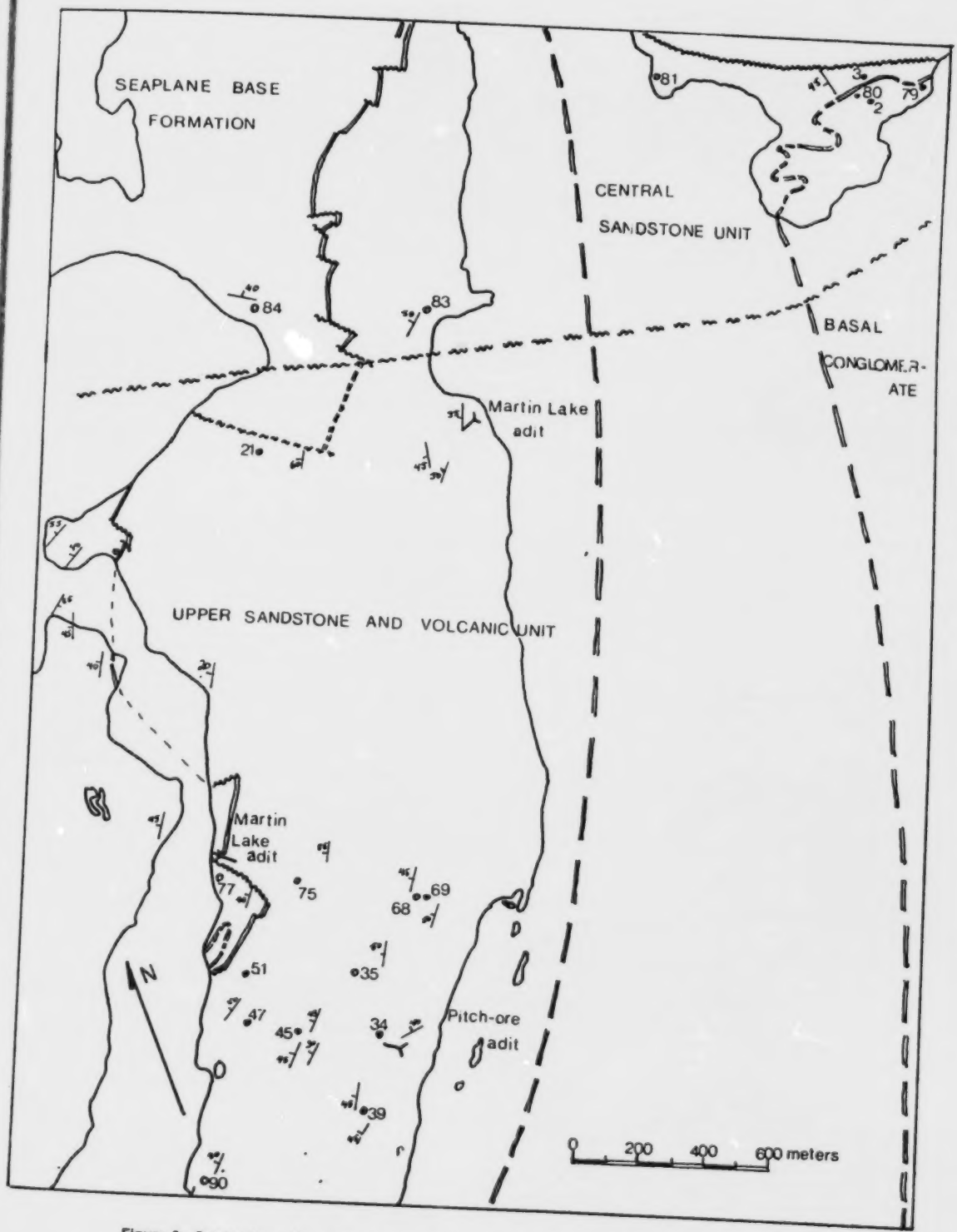

Figure 3—Subdivisions of the Gillies Channel Formation. Numbered outcrops are referred to in text.

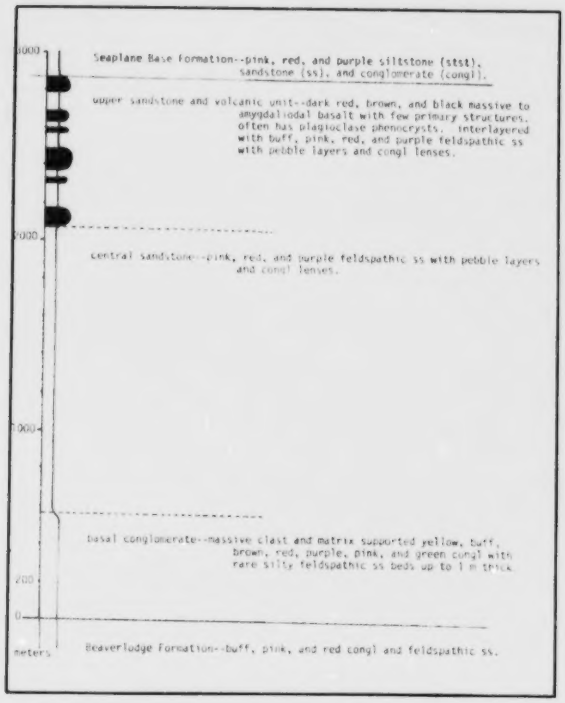
Seaplane Base Formation--pink, red, and purple siltstone (stst), sandstone (ss), and conglomerate (congl).
upper sandstone and volcanic unit--dark red, brown, and black massive to amygdaloidal basalt with few primary structures, often has plagioclase phenocrysts; interlayered with buff, pink, red, and purple feldspathic ss with pebble layers and congl lenses.
central sandstone--pink, red, and purple feldspathic ss with pebble layers and congl lenses.
basal conglomerate--massive clast and matrix supported yellow, buff, brown, red, purple, pink, and green congl with rare silty feldspathic ss beds up to 1 m thick.
Beaverlodge Formation--buff, pink, and red congl and feldspathic ss.
1000
800
600
400
200
0
meters

Figure 4 – Stratigraphic section of the Gillies Channel Formation

cherty appearance and, seen in thin section, the matrix is composed mostly of cryptocrystalline quartz cementing angular quartz grains. The remaining minerals are fresh chlorite and white mica sheaves, which make up 15 percent of the matrix, with 5 percent hematite colouring the rock pale purple. At outcrop 2, 100 m west, on the other hand, the matrix has up to 60 percent earthy hematite.

East of Padget Bay the Gillies Channel Formation is bounded to the north by the ABC Fault. Fracturing and alteration of the rocks in this area have all but obliterated the original nature of the conglomerate. Near the base of the section (outcrop 79), siliceous veins up to 4 cm wide form a close-spaced network. Moving up the section, hematite and clay become more abundant and, near the top (outcrops 2 and 80), shears and fractures are filled with massive earthy hematite. Throughout the unit, calcite and hematite fill fractures and coat exposed surfaces of the rock.

Central Sandstone

The central sandstone lies almost entirely beneath Beaverlodge Lake and was seen only on the east side of Padget Bay. It is probably 800 to 1500 m thick and is composed of feldspathic sandstone with conglomerate lenses and pebble layers. The contact between the central sandstone and basal conglomerates is gradational over a few metres.

At outcrops 3 and 81 near the east corner of the map, pink, red and purple sandstones with pebble layers and conglomerate lenses up to 50 cm thick form sequences much like those of the sediments in the upper sandstone and volcanic unit.

Outcrop 3 is composed of 40 percent quartz, 7 percent feldspars, 3 percent white mica and clay aggregates, with a few grains of anatase. Grain sizes range from 0.25 to 1.5 mm, the largest grains being quartz. The matrix is predominantly clay-sized grains (50 percent), with 40 percent calcite, 20 percent hematite and 10 percent fresh chlorite and white mica sheaves.

The sandstone at outcrop 81 is well packed with 60 percent quartz, 40 percent feldspars and trace amounts of garnet and anatase. Grain sizes vary from 0.01 to 1.0 mm. The matrix makes up 20 percent of the rock, and is 50 percent hematite, 20 percent clay-sized grains and 20 percent fresh chlorite and white mica sheaves, with only a trace of calcite. The rock is red with irregular buff-coloured spots cemented almost entirely by chlorite and white mica.

The grains in both outcrops 3 and 81 are angular to subrounded and show extensive pressure solution but no quartz or feldspar overgrowths. The quartz grains are fresh and vary from undeformed to undulose grains and mosaic aggregates. The feldspars are microcline, microperthite and plagioclase, and many are highly sericitized. Granitic lithic clasts containing quartz and feldspars are present but rare.

Upper Sandstone and Volcanic Unit

The upper unit of the Gillies Channel Formation (Fig. 5) is composed of feldspathic sandstones and mafic flows, has a thickness of 800 m and is well exposed between Beaverlodge and Martin Lakes. The lower boundary of the unit, which lies beneath Beaverlodge Lake, is at the base of the first of six volcanic units interlayered with the sandstones. Figures 6 to 10 show lithological sequences typical of all the sediments in the middle and upper units of the formation.

The sedimentary sequences of the upper unit are pink, red and purple sandstones with

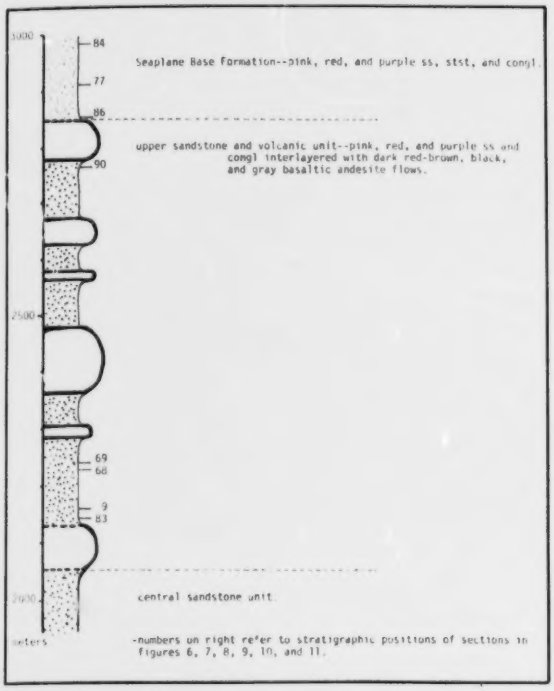
3000
2500
2000
meters
84
77
86
90
69
68
9
83
Seaplane Base formation--pink, red, and purple ss, stst, and congl.
upper sandstone and volcanic unit--pink, red, and purple ss and congl interlayered with dark red-brown, black, and gray basaltic andesite flows.
central sandstone unit.
-numbers on right refer to stratigraphic positions of sections in figures 6, 7, 8, 9, 10, and 11.

Figure 5—Stratigraphic section of the upper sandstone and volcanic unit of the Gillies Channel Formation.

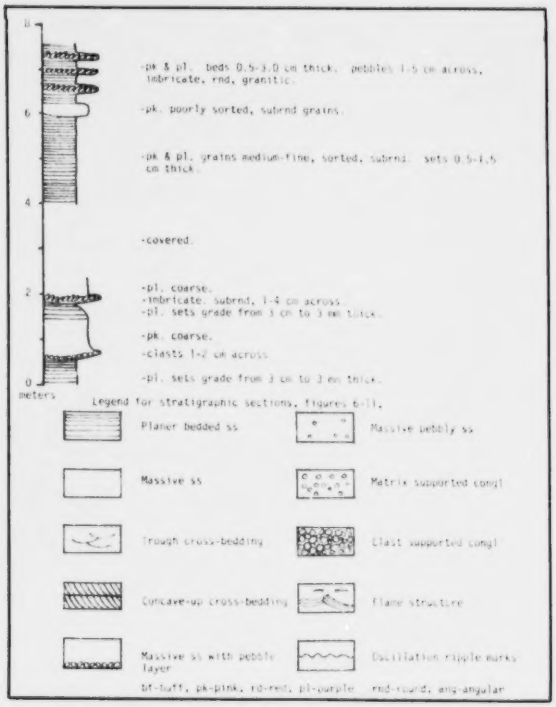

Figure 6—Stratigraphic section of outcrop 83.

pebble layers and conglomerate lenses. The sandstones are generally well indurated, well packed and poorly sorted. Grain sizes vary from 0.01 to 2.0 mm, the largest being angular to rounded quartz grains and mosaic aggregates which comprise 30 to 40 percent of the rock. Pink to red plagioclase, microcline and microperthite grains comprise 20 to 40 percent of the rock and are more rounded than the quartz grains. The feldspars are typically highly sericitized. Pressure solution is a common feature but quartz and feldspar overgrowths are rare.

Grains of opaque minerals, anatase, garnet, apatite, zircon, epidote, white mica and biotite are all present in trace amounts. Hematite and calcite fill veins up to 2 mm wide and are the most common cement, but fresh chlorite and white mica sheaves, and clay-sized grains may form up to 20 percent of the rock.

Conglomerate beds are mostly 5 cm to 1 m thick and vary from clast supported to matrix supported. They are commonly unsorted lenses of round to subangular quartz and granitic clasts 1 to 20 cm across in a matrix of sandstone. Clasts of Gillies Channel volcanics are found above some flows (outcrops 47, 51 and 75, east and southeast of Martin Lake adit) where, for the space of a few metres, large numbers of angular mafic clasts rest in a matrix of poorly sorted homogeneous pink and red sandstone and round quartz and granitic pebbles.

Depending on cementing material, the sediments vary from buff to pink, red and purple. Hematite staining usually follows bedding, concentrating in finer-grained layers, but also cuts across beds regardless of their lithology. In many stained beds there are spots of greenish or greyish sandstone 1 mm to 2 cm across that are cemented by calcite, chlorite and white mica.

The sandstones and conglomerates are intimately interbedded and lithologies vary laterally and vertically over short distances. Any one bed can be traced at most for a few metres before it is truncated by a scour surface or pinches out. Typical sequences contain bedded pink and purple sandstone; pebbly massive and/or crossbedded pink sandstone; flaggy laminar buff, pink and red sandstone; clast- or matrix-supported conglomerate lenses; and pebble layers. These components are commonly arranged in upward fining sequences one or two metres thick bounded top and bottom by curved scour surfaces (Figs. 6, 7, 8, 9 and 10).

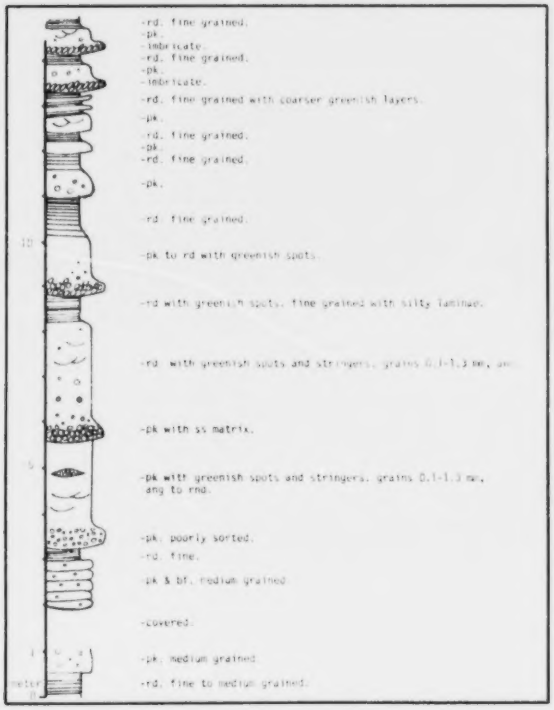

Figure 7—Stratigraphic section from the Martin Lake Mine adit (outcrop 9)

Sequences of immature clastic sediments of this type are thought to represent the channel deposits of a proximal river system.

Primary structures include planar and plane laminar bedding, graded beds, trough and concave-up crossbedding with sets 10 to 25 cm thick and foresets 0.5 to 2 cm thick, scour-and-fill structures (commonly with pebbly lag deposits at the base), flame structures, and imbricate pebble layers. Planar and plane laminar beds in sets 0.5 to 10 cm thick are the most common structures. Bedding is distinguished by scour surfaces, variations in colour and grain size, and flaggy partings.

Tops face west as determined from graded beds, pebble draping, drop-stones, crossbedding and beds truncated by scour surfaces. Measurements of transport direction indicate that sediment provenance was from the east, which is in keeping with the more extensive measurements made by Tremblay (1972).

The Gillies Channel volcanics are dark red-brown, black and grey basaltic andesites (Nockolds et al., 1976) that are typically amygdaloidal and in part porphyritic. In hand specimen, euhedral laths of plagioclase, often occurring as birdsfoot clusters up to 1 cm across, are generally the only visible mineral. The smaller laths are dark coloured, whereas the larger crystals are white or stained red. On an island near the south shore of Martin Lake to the south of the map area, the volcanic flows contain euhedral hornblende phenocrysts up to 2 mm wide.

In thin section the plagioclase occurs in laths (An_{29-32}) in the groundmass as well as in megascopic form. Together these make up an average 50 percent of the rock. Opaque matrix minerals comprise 27 percent and chlorite, as disseminated sheaves in the groundmass as well as in euhedral aggregates that may be psuedomorphs after hornblende, some 13 percent. Accessory minerals include calcite, apatite, sphene and epidote. At one location (outcrop 21, west of Martin Lake mine adit), euhedral apatite phenocrysts up to 1.2 mm long make up almost 10 percent of the rock.

Amygdules, while locally absent, are found throughout the volcanics. Most are spherical and 1 to 4 cm in diameter, although stretched amygdules are found close to the tops of some flows. Fillings are of calcite, chlorite, earthy and specular hematite, fluorite and cryptocrystalline quartz. At the Martin Lake adit, a 4 cm amygdule is filled with calcite and rimmed by drusy purple fluorite. At outcrop 34 near the Pitch-ore adit, amygdules are filled by chlorite rimmed successively by calcite and specular hematite. Various other combinations have been noted, but generally calcite and chlorite form the secondary fillings within rims of quartz, hematite and fluorite.

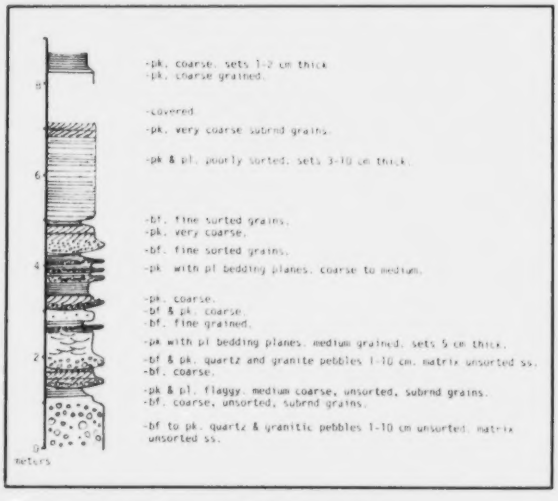
-pk, coarse, sets 1-2 cm thick
-pk, coarse grained.
-covered.
-pk, very coarse subrnd grains.
-pk & pl, poorly sorted, sets 3-10 cm thick.
-bf, fine sorted grains.
-pk, very coarse.
-bf, fine sorted grains.
-pk with pl bedding planes, coarse to medium.
-pk, coarse.
-bf & pk, coarse.
-bf, fine grained.
-pk with pl bedding planes, medium grained, sets 5 cm thick.
-bf & pk, quartz and granite pebbles 1-10 cm, matrix unsorted ss.
-bf, coarse.
-pk & pl, flaggy, medium coarse, unsorted, subrnd grains.
-bf, coarse, unsorted, subrnd grains.
-bf to pk, quartz & granitic pebbles 1-10 cm unsorted, matrix unsorted ss.
8
6
4
2
0
meters

Figure 8—Stratigraphic section of outcrop 68

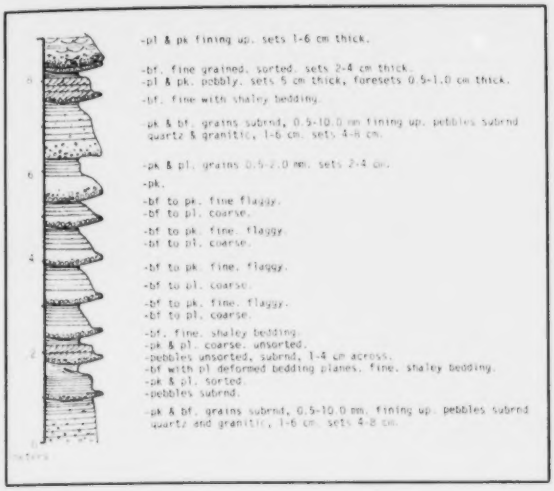
-pl & pk fining up, sets 1-6 cm thick.
-bf, fine grained, sorted, sets 2-4 cm thick.
-pl & pk, pebbly, sets 5 cm thick, foresets 0.5-1.0 cm thick.
-bf, fine with shaley bedding.
-pk & bf, grains subrnd, 0.5-10.0 mm fining up, pebbles subrnd quartz & granitic, 1-6 cm, sets 4-8 cm.
-pk & pl, grains 0.5-2.0 mm, sets 2-4 cm.
-pk.
-bf to pk, fine flaggy.
-bf to pl, coarse.
-bf to pk, fine, flaggy
-bf to pl, coarse.
-bf to pk, fine, flaggy.
-bf to pl, coarse.
-bf to pk, fine, flaggy.
-bf to pl, coarse.
-bf, fine, shaley bedding.
-pk & pl, coarse, unsorted.
-pebbles unsorted, subrnd, 1-4 cm across.
-bf with pl deformed bedding planes, fine, shaley bedding.
-pk & pl, sorted.
-pebbles subrnd.
-pk & bf, grains subrnd, 0.5-10.0 mm, fining up, pebbles subrnd quartz and granitic, 1-6 cm, sets 4-8 cm.
8
6
4
2
0
meters

Figure 9 – Stratigraphic section of outcrop 69.

Primary structures are rare in the flows. Flow top breccia was seen in outcrop 75 southeast of the Martin Lake adit, but its presence can be inferred elsewhere where the upper contacts have been weathered out. At one location (outcrop 45, north of the Pitch-ore adit), bulbous structures weathered out in relief near the base of the flow have been interpreted as flow tubes, but no pillows were found. The abundance of amygdules, brecciated flow tops and the absence of pillows are compatible with subaerial extrusion.

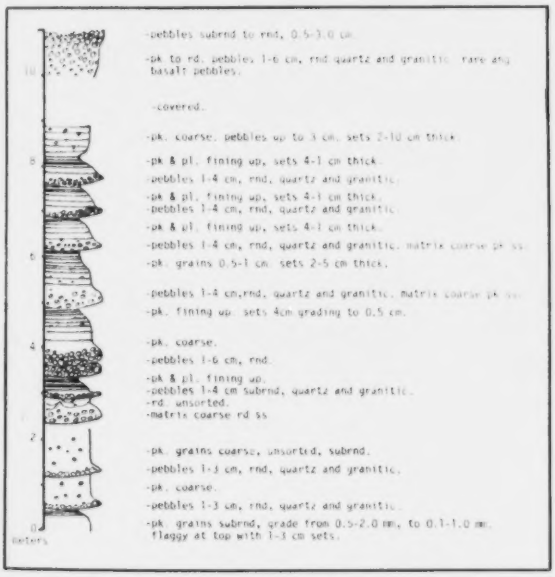
-pebbles subrnd to rnd, 0.5-3.0 cm.
-pk to rd, pebbles 1-6 cm, rnd quartz and granitic, rare any basalt pebbles.
-covered.
-pk, coarse, pebbles up to 3 cm, sets 2-10 cm thick.
-pk & pl, fining up, sets 4-1 cm thick.
-pebbles 1-4 cm, rnd, quartz and granitic.
-pk & pl, fining up, sets 4-1 cm thick.
-pebbles 1-4 cm, rnd, quartz and granitic.
-pk & pl, fining up, sets 4-1 cm thick.
-pebbles 1-4 cm, rnd, quartz and granitic, matrix coarse pk ss.
-pk, grains 0.5-1 cm, sets 2-5 cm thick.
-pebbles 1-4 cm,rnd, quartz and granitic, matrix coarse pk ss.
-pk, fining up, sets 4cm grading to 0.5 cm.
-pk, coarse.
-pebbles 1-6 cm, rnd.
-pk & pl, fining up.
-pebbles 1-4 cm subrnd, quartz and granitic.
-rd, unsorted.
-matrix coarse rd ss
-pk, grains coarse, unsorted, subrnd.
-pebbles 1-3 cm, rnd, quartz and granitic.
-pk, coarse.
-pebbles 1-3 cm, rnd, quartz and granitic.
-pk, grains subrnd, grade from 0.5-2.0 mm, to 0.1-1.0 mm, flaggy at top with 1-3 cm sets.
10
8
6
4
2
0
meters

Figure 10 – Stratigraphic section of outcrop 90.

The flows are all concordant with the sediments, and contacts are planar to gently undulating. Because of the numerous closely spaced faults (expressed on the ground by small steep-walled gullies), it is impossible to trace individual flows laterally for any distance. There are six separate extrusive events represented, but individual units may represent more than one outpouring of lava.

Calcite, drusy quartz, and hematite veins and stringers, in places accompanied by uranium mineralization (Martin Lake adit), cut the outcrops and are concentrated mostly near the tops and bottoms of the flows. Veins at the base of flows may extend a few centimetres into the underlying sediments, and networks of calcite or hematite veinlets locally permeate shear zones (outcrops 35 and 39, near Pitch-ore adit).

The Seaplane Base Formation consists of pink, red and purple sandstones, siltstones and conglomerates distinguishable from underlying Gillies Channel rocks by their brighter colours and thick sequences of ripple-marked siltstones. Otherwise, the Seaplane Base Formation is very similar to the Gillies Channel sediments, as can be seen by comparison of Figures 6 to 10 with the stratigraphic sections shown in Figure 11. Langford (1981) included in the Gillies Channel Formation the 200 to 400 m of the sediments above the top flow. In this report, however, the upper contact of the Gillies Channel Formation has been placed at the top of the last flow because of the lack of distinct and continuous horizons within the overlying sediments. The top of the upper flow is easily traceable and, because it represents the cessation of volcanic activity in the basin, appears to have some stratigraphic significance.

Geological History

The basal conglomerate was deposited in alluvial fans of braided rivers running off the granitic highlands to the north and east of the Martin Basin. As relief decreased this conglomerate was overlain by finer channel deposits of the central and upper sandstones. Volcanic activity accompanied the deposition of the upper sandstone, and the 20 to 120 m thick mafic flows were covered by fluviatile sediments soon after they were extruded. As the rivers flowed over the volcanics, clasts of the brecciated flow tops were ripped up and redeposited just above the flows in a matrix of feldspathic sandstone.

The subsequent folding and faulting of the Gillies Channel Formation were not

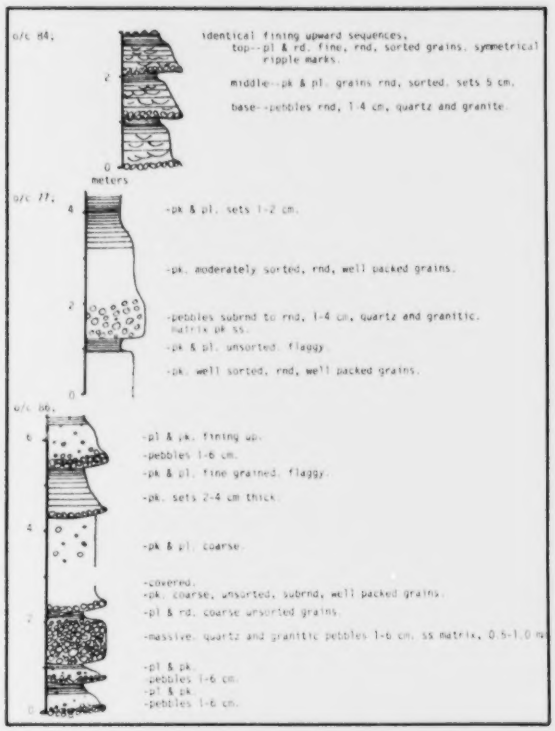
o/c 84.
identical fining upward sequences;
top--pl & rd. fine, rnd, sorted grains, symmetrical ripple marks.
middle--pk & pl. grains rnd, sorted, sets 5 cm.
base--pebbles rnd, 1-4 cm, quartz and granite.
meters
o/c 77.
-pk & pl. sets 1-2 cm.
-pk, moderately sorted, rnd, well packed grains.
-pebbles subrnd to rnd, 1-4 cm, quartz and granitic. matrix pk ss.
-pk & pl, unsorted, flaggy.
-pk, well sorted, rnd, well packed grains.
o/c 86.
-pl & pk, fining up.
-pebbles 1-6 cm.
-pk & pl, fine grained, flaggy.
-pk, sets 2-4 cm thick.
-pk & pl, coarse.
-covered.
-pk, coarse, unsorted, subrnd, well packed grains.
-pl & rd, coarse unsorted grains.
-massive, quartz and granitic pebbles 1-6 cm, ss matrix, 0.5-1.0 m
-pl & pk
-pebbles 1-6 cm.
-pl & pk
-pebbles 1-6 cm.

Figure 11 – Stratigraphic sections of outcrops 86, 77 and 84.

accompanied by metamorphism, but deuteric alteration of the flows (Tremblay, 1972) resulted in the replacement of mafic minerals by hematite, calcite and chlorite. The abundance of feldspars in the sediments indicates that little chemical weathering accompanied their transport and deposition, and points to the existence, in the original detritus, of unstable mafic minerals whose solution may account for much of the hematite, chlorite and white mica now present in the sandstones.

Acknowledgements

This project was funded by a NSERC grant and supervised by F.F. Langford of the Department of Geological Sciences at the University of Saskatchewan. Room, board and transportation in the field were provided by the Saskatchewan Geological Survey. An original draft of this paper was reviewed by F.F. Langford, and his advice and assistance, along with that of D. Thomas, M. Goulding and D. Smith are gratefully acknowledged.

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ECONOMIC GEOLOGY INVESTIGATIONS

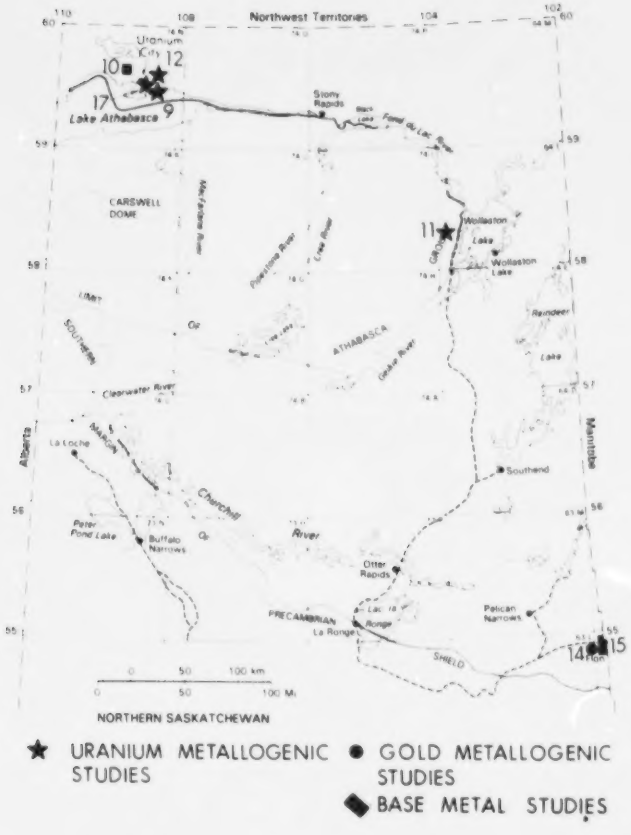

Figure 1—Location of divisional[1] Economic Geology Projects reported here Numbers on map refer to projects listed below.

Project No.	Area/Short Title	Project Leader(s)
Uranium Metallogenic Studies:		
8209	Nicholson Bay Area	T.I.I. Sibbald
8211	Dawn Lake	C.T. Harper
8212	Mickey Lake Area	D.J. Thomas
8217	Gillies Channel Formation, Martin Group	D.J. Thomas
Gold Metallogenic Study:		
8214	Amisk Lake East	J.G. Pearson
Base Metal Studies:		
8210	Dianne Lake	B.P. Scott
8215	Flin Flon Base Metals Project[2], Hamell Lake Area	G.R. Parslow and J.W. Gaskarth

[1]Economic geology projects by other institutions not included unless directly funded.
[2]Contracted to the University of Regina.

Introduction by T.I.I. Sibbald

The Economic Geology Division undertook six field projects (Fig. 1) of which five involved staff members on a part- or full-time basis and one was contracted to the University of Regina.

Uranium Metallogenetic Studies

Programs were carried out at Dawn Lake and in the Uranium City area. The Dawn Lake investigation (Project 8211) involved logging and sampling of 'typical' cores from drill hole cross-sections of the 11, 11A, 11B and 14 ore zones. Characteristics of primary and alteration lithologies and of the uranium-nickel-cobalt-copper mineralization(s) were documented.

Several studies were implemented in the Uranium City area as part of Project Beaverlodge (Macdonald, this volume).

At Nicholson Bay, on the north shore of Lake Athabasca, 16 km southeast of Uranium City, an area encompassing several uranium and gold occurrences including some past producers was geologically mapped at 1:20,000 scale (Project 8209). In addition, the major occurrences of economic minerals were examined. Mapping revealed a small previously unrecognised, outlier of the Athabasca Group on the west shore of Nicholson Bay. Also encountered were several bodies of ultramafic rock and dykes of beryliferous pegmatite not previously documented in official reports. Geological relationships observed in the Athabasca Group sediments and the adjacent uranium occurrences indicate a probable post-Athabasca age for the uranium mineralization in this area.

The Mickey Lake area, located 15 km northeast of Uranium City and 3 km north of the Ace-Fay-Verna deposits, was mapped at 1:10,000 scale (Project 8212). The project is designed to re-evaluate and refine existing geological understanding with respect to uranium metallogenesis and is an extension of a study begun in the adjacent Donaldson Lake area in 1981.

Bedrock sampling (Project 8217) of the interbedded arkoses and basalt-andesite volcanics of the Gillies Channel Formation was also undertaken. This project has the primary objective of determining the petrography and chemistry of the volcanics and hence of establishing their eruptive environment. The chemistry of subsequent alteration events associated with emplacement of pitchblende mineralization will also be examined.

Gold Metallogenetic Studies

The Creighton resident geologist continued gold studies around Flin Flon by mapping and sampling five gold prospects (Amisk Syndicate, Mitchell, Mosher Lake, Sye and Robinson Creek) in the Amisk Lake east area (Project 8214). Gold mineralization in the area is mostly associated with northwesterly trending quartz-carbonate vein systems, surrounded by carbonate, silica and tourmaline alterations. Possibly emplaced synchronously with a period of granodiorite plutonism, the veins appear to have been remobilized by a later fold/fault event.

Base Metal Studies

As part of Project Beaverlodge, an examination of copper-silver mineralization at Dianne Lake, 15 km northwest of Uranium City, was carried out through detailed 1:1,200 scale geological mapping of the property, bedrock sampling, mapping and sampling of trenches and pits and 1:63,360 mapping of the area surrounding the property (Project 8210). The low grade copper-silver mineralization is typically hosted by garnet-biotite gneisses and occurs in two zones in conformable, near horizontal, concentrations and in sub-vertical east-northeast trending fractures. High grade silver mineralization in association with cobalt and nickel is found locally in one of the zones in northerly trending sub-vertical fractures.

Under the Flin Flon base metals project (8215), contracted to the University of Regina, metavolcanic rocks in the Hamell Lake area were sampled. The 500 bedrock samples collected will be analysed for major and selected trace metals to enable definition of their composition, evolution and depositional environment. Analytical results will be compared with those from surrounding areas, Amisk Lake east, Annabel Lake and Hanson Lake.

Mineralized Core Collection

An aggressive program of core collection continued during the year, with the objective

of establishing a record of northern Saskatchewan's mineral deposits and other important geological features, such as stratigraphic core from the Athabasca Basin. Rock suites from several mineral prospects, illustrating host rocks and mineralizations, were also assembled by the resident geologists to augment the core collection. The value of such collections has been amply demonstrated by the enthusiastic response of the mineral industry to core displays held in conjunction with the various geological symposia recently hosted by the Province. The cooperation of the companies who submitted core is gratefully acknowledged.

Mineral Deposits Index

Work on the Saskathewan Mineral Deposits Index continued, irrespective of staff shortage. Manual and computer files have been completed, although these are the subject of continuous updating.

Resident Geologists Offices

The Economic Geology Division, through the resident geologists in La Ronge, Creighton and Uranium City, and the staff of the Regina office, services the mining industry by providing up-to-date information on exploration and mining opportunities and activities in northern Saskatchewan. Numerous meetings with industry representatives were held during the year and several field visits undertaken. The resident geologist offices continue to maintain files of current mineral claim maps, airphotos and assessment work submissions for their respective districts, and to sell geological maps and reports.

Uranium Metallogenic Studies: Nicholson Bay Area

by T. I. I. Sibbald

The study area lies 15 km to the southeast of Uranium City within UTM sheet 6400-65900 and surrounds Nicholson Bay on the north shore of Lake Athabasca.

The area has been mapped by the Geological Survey of Canada at scales as detailed as 1:4800 (1"x400') (Alcock, 1936; Joliffe, 1946; Christie, 1953 and Tremblay, 1972). In addition, parts of the area have been subjected to extremely detailed investigations in connection with mineral exploration programs and mining developments. Descriptions of the various mineral occurrences are provided by several writers (Alcock, 1936; Christie,1953; Robinson, 1955; Griffith, 1967; Beck, 1969 and Tremblay, 1972). The present investigation is a continuation of work carried out in the adjacent Lodge Bay area (Sibbald and Lewry, 1980) and is designed to elucidate regional stratigraphic, structural and metamorphic relationships and aid in the genetic interpretation of mineral deposits in the region.

The field program comprised the following:

1) 1:20,000 scale geological mapping of the area surrounding Nicholson Bay.

2) Examination and geochemical sampling of the major economic mineral occurrences in surface outcrops and mine waste piles.

3) Regional sampling of bedrock, particularly granitoids, for petrological and geochemical investigations.

4) Sampling of the Box, Frontier, Lodge Bay (Sibbald and Lewry, 1980) and McKintosh Bay granitoids and Moose Island beryliferous pegmatites for an ongoing geochronology program in the Beaverlodge area.

Among the more interesting new observations resulting from the field program are the following:

1) Athabasca Group sediments are exposed in a small outlier on the west side of Nicholson Bay.

2) Ultramafic rocks outcrop on the east side of Nicholson Bay, in Fish-hook Bay and north and west of Cornwall Bay.

3) Beryliferous granite pegmatites cut the McKintosh Bay-Moose Island granite and the intervening supracrustal rocks in the Moose Island area.

Athabasca Group (Nicholson Bay)

The Athabasca Group is present as scattered outcrops on the west shore of Nicholson Bay over an area of 200 x 100 m^2, and overlies "ferruginous quartzites" (Christie, 1953) of the metamorphic basement. It is probably no more than a few metres in exposed thickness and comprises breccias and sandstones. The breccias are typified by angular pebble and cobble-sized fragments of white (basement) quartzite, set in a pink to grey medium grained sand matrix. The sandstones are, as the breccia matrix, pink to grey, medium grained, well cemented and poorly bedded. The Athabasca sediments are cut by veins and invaded by irregular replacements of brown 'chert'.

The underlying ferruginous quartzites are formed in part by cherty quartzite breccia containing angular relicts of white quartzite in a red-brown to brown 'cherty' replacement matrix, and in part by hematitic white quartzite, which is fractured and vuggy. The fractures and vugs are coated and filled by euhedral quartz, hematite (specularite) and white euhedral carbonate. Cherty replacement is locally so pervasive that 'Athabasca breccia' and 'basement breccia' are indistinguishable.

Ferruginous quartzites are well developed around Nicholson Bay and south of the toe of Cornwall Bay, areas characterized also by numerous uranium occurrences, which typically display complex mineralogy (eg. pitchblende $\pm$ coffinite + thucolite + Ni-Co-arsenides and sulphides $\pm$ native gold and silver).

Examination of the major occurrences shows hematization, chloritization and silicification (chertification) to be characteristic wall rock alterations of the uranium-bearing veins. In surface trenches of the Nicholson No. 4 zone (Christie, 1953), pitchblende-bearing white carbonate veins, which also contain nickel-cobalt-arsenides, are observed cross-cutting cherty wall rock alteration. Similar relationships are apparent in other occurrences.

The following time sequence is indicated by the field observations:

1) Deposition of the Athabasca Group.

2) Alteration (chertification, etc.) of the Athabasca Group and underlying basement quartzite (in response to diagenetic processes in the Athabasca Group ?).

3) Deposition of pitchblende veins of complex mineralogy.

This sequence of events lends credence to the argument proposed by Hoeve (1978) and Hoeve and Sibbald (1978), that two distinct generations of uranium deposits, reflecting entirely different episodes of metallogenesis, are present in the Beaverlodge district. Deposits of simple mineralogy, formed 1740 my ago, are thought to be of Hudsonian metamorphic-hydrothermal origin (Beck, 1969), whereas those of complex mineralogy developed, possibly 1100 my ago, coevally with unconformity-type deposits in the Athabasca Basin.

Ultramafic Rocks

Ultramafic rocks form apparently concordant bodies several tens of metres thick interlayered with calcareous quartzites and carbonates in the Fish-hook Bay area and with amphibolites and hornblendic rocks north and west of Cornwall Bay. The ultramafics east of Nicholson Bay are underlain by a zone of sulphide mineralization hosted by intermixed calcareous quartzites, calc-silicates and carbonates. They appear to be interlayered with medium-grained massive amphibolite.

The ultramafics are typically buff to pale blue weathering, green-black when fresh and composed of fine-grained serpentine minerals, in which knotty aggregates of pale green amphibole (tremolite?) are developed. Locally the pale coloured amphibole is predominant. The ultramafic rocks are commonly massive, however, talcose schistose zones occur sporadically. Fractures are typically filled by asbestiform minerals and in the Fish-hook Bay body by hematite (specularite). It is uncertain whether these rocks are hypabyssal or volcanic.

In view of an apparent spatial association of ultramafic rocks with gold mineralization (Pyke, 1980, Fox and Johnston, 1980), the presence of such rocks in proximity to the gold mining camp of Goldfields may be significant.

Gold mineralization is hosted by late granitoid rocks cut by quartz veins at Goldfields. Gold occurs predominantly in the quartz veins, in pyrite at the Box Mine and as free gold at the Athona Mine in association with galena, sphalerite and chalcopyrite. Numerous other less significant occurrences of gold-bearing quartz veins are recorded in granitic rocks of the area (Alcock, 1936; Christie, 1953). Gold is also found in pitchblende-bearing veins in the Nicholson and Fish-hook Bay areas (Christie, 1953; Robinson, 1955). This association is younger in age and is common to many uranium occurrences of unconformity-type.

Recent Rb-Sr geochronological work on the Box granite yields an age of 2155±40 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.729±0.007 (Bell and Blenkinsop, this volume). The high initial ratio indicates derivation of the granite and presumably of the contained gold from an older crustal source. There is little evidence that exploration programs undertaken to date have been designed to locate such a source, whether it be in the volcanic or hypabyssal rocks, in the interlayered sediments or in the oxide and sulphide facies iron formations, present in the area.

Beryliferous Pegmatites

Beryliferous granite pegmatite dykes up to a few metres thick cross-cut the McKintosh Bay - Moose Island granite and the intervening supracrustal rocks. The dykes are white to pink, of medium- to pegmatitic-grain size and comprise quartz, feldspars, muscovite, tourmaline (schorlite) and beryl, together with several unidentified minerals. Beryl occurs as pale yellow-green hexagonal crystals up to 1 cm long. Dykes occasionally show textural and mineralogical zoning, with pegmatitic margins and medium-grained cores and with concentrations of different mineral phases (eg. tourmaline) in zones parallel to the dyke walls. Walls of fractures cross-cutting the granites occasionally show tourmalinization.

The beryliferous pegmatites indicate a potential for associated concentrations of rare earth elements, tin, tungsten, uranium and molybdenum.

Bedrock samples, particularly of the granitoid rocks, collected during the 1980 field season in the adjacent Lodge Bay area (Sibbald & Lewry, 1980), have been analyzed to determine granophile element concentrations. Samples collected during routine mapping traverses, have been analyzed quantitively for Sn, F, Li, K, Na, Rb, Sr and Au and semi-quantitively for a wide range of other elements. Although some

anomalous gold values were obtained, concentrations of the granophile elements appear normal.

Regional geological considerations and the recognition of two-mica granites in the Lodge Bay area formed the rationale for this analytical program. The discovery of the beryliferous pegmatites lends it support, in retrospect, and indicates a need for lithogeochemical studies, also in the Nicholson Bay area.

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Uranium Metallogenic Studies: Dawn Lake Property

by C. T. Harper

A study was initiated at the Dawn Lake property, operated by Asamera Inc. in joint venture with the Saskatchewan Mining Development Corporation, SERU Nucleaire (Canada) Ltee. and Reserve Oil and Minerals Corporation, which included:

1) examination of diamond drill cores from representative cross-sections of the 11A and 14 Zones and from other selected holes in these zones and in the 11 and 11B Zones;

2) sampling of drill core for petrographic and geochemical studies.

The results presented here are limited to the field aspects of this study.

Description of Rock Types

The basement geology in the vicinity of the Dawn Lake uranium deposits is largely interpreted from regional geophysical surveys. The deposits, which are located in an area of low magnetics far from suspected Archean gneiss domes are thought to be underlain by stratigraphically higher Aphebian Wollaston Group rocks than most of the other nearby uranium deposits such as Midwest Lake, McClean Lake and Collins Bay, which lie in close proximity to the Archean/Aphebian contact (Fig. 1) (Sibbald, 1980; Clarke and Fogwill, 1981 and in prep).

The basement rocks in the Dawn Lake area occur below about 70 m of Athabasca Group sediments

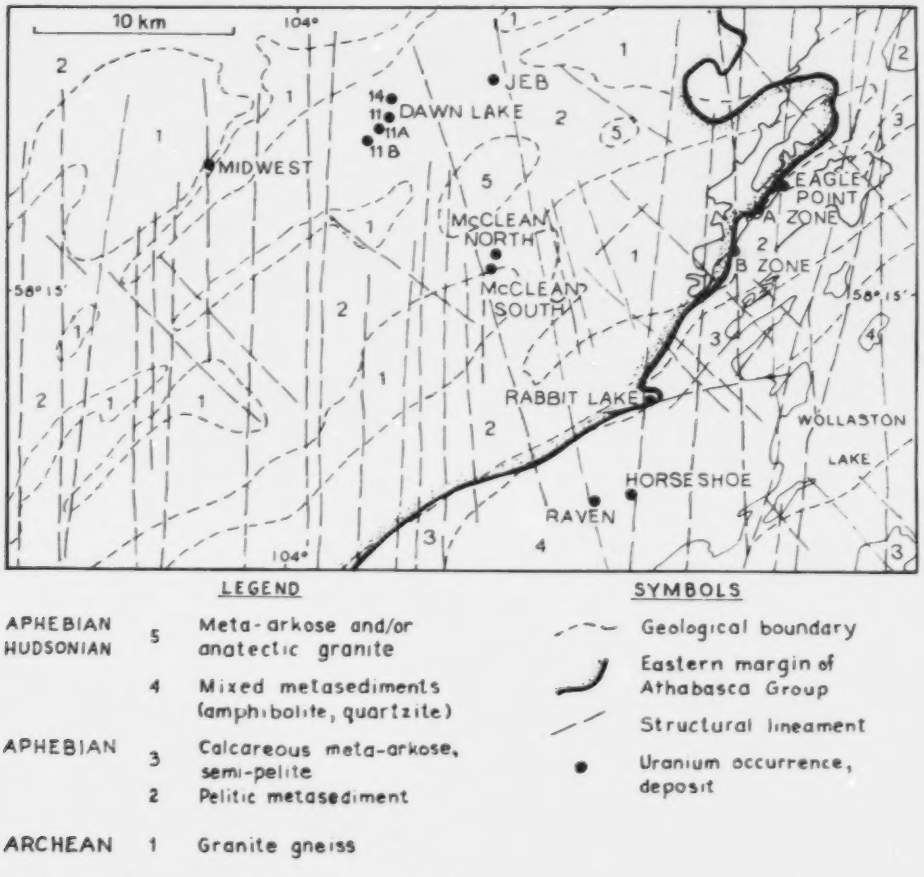

Figure 1 – Interpretive geology of the sub-Athabasca Group basement in the NEA-IAEA Test Area (after Sibbald, 1980).

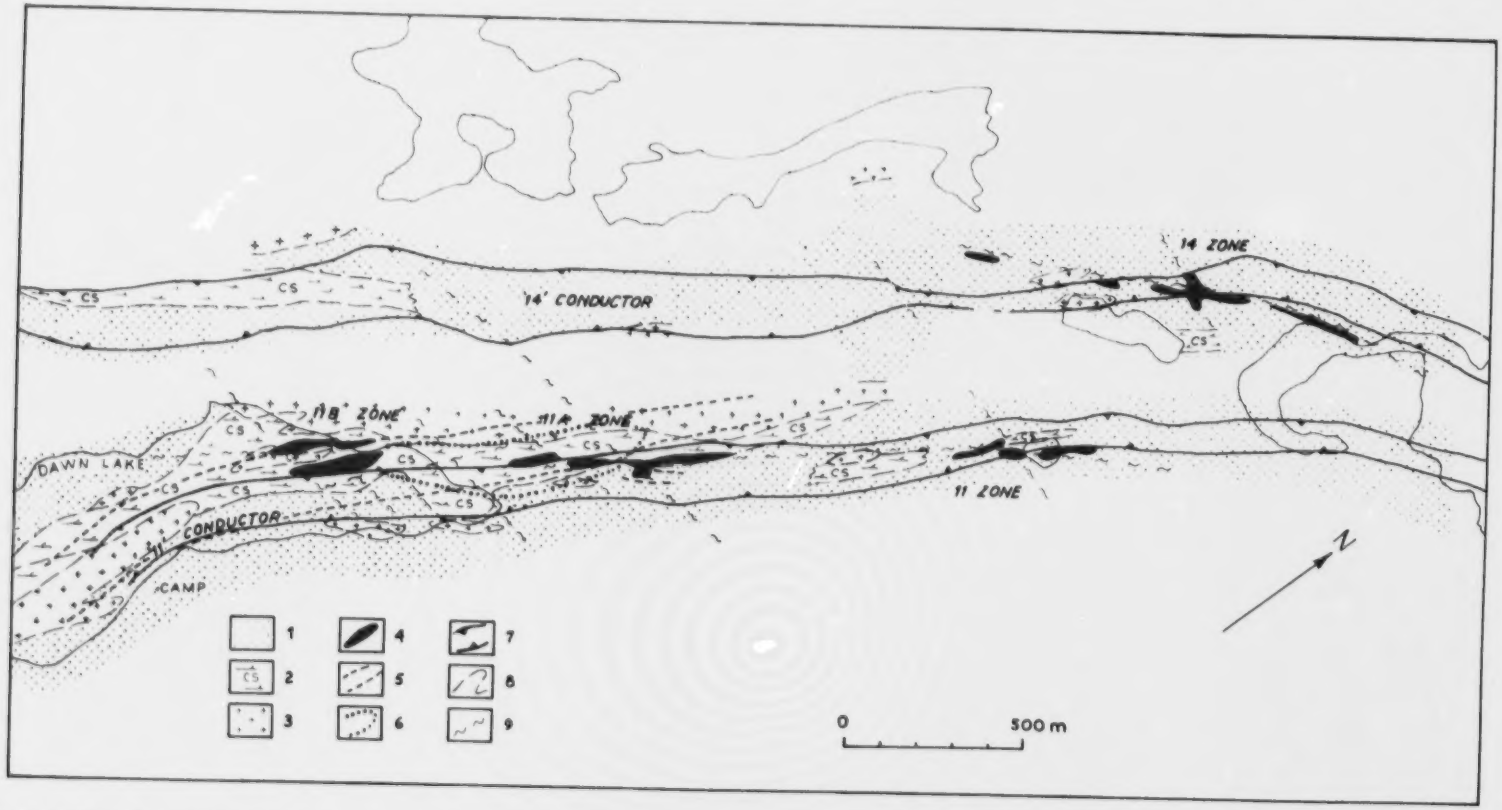

Figure 2—Generalized basement geology and location of the uranium deposits, Dawn Lake area (modified from Clark and Fogwill, 1981 and in prep.). 1, pyritic-graphitic pelitic and semipelitic gneiss; 2, calc-silicate rocks; 3, pegmatite; 4, uranium mineralization; 5, outline of copper-enriched zone; 6, outline of cobalt-enriched zone; 7, pulse electromagnetic (PEM) conductor; 8, geological contact; 9, fault.

and 30 m of glacial overburden. They comprise a sequence of subvertically dipping graphitic, pyritic pelitic and semipelitic schists and genisses, graphitic and in places silicified calc-silicate and carbonate rocks, minor psammitic rocks and semiconcordant granite pegmatite sheets and lenses which locally contain tourmaline.

The pelitic rocks are typically dark grey, fine to medium grained (0.5 to 3.0 mm), well foliated and composed of biotite (10 to 40 percent), quartz (20 to 30 percent), feldspar (20 to 40 percent), graphite (2 to 10 percent) and pyrite (0 to 10 percent). Bluish-green elipsoidal grains (from 1 to 5 mm long) are believed to be cordierite and locally comprise up to 20 percent of these rocks. Sillimanite faserkiesel, 1 to 2 mm long, garnet porphyroblasts up to 1 cm in diameter, millimetre-sized tourmaline crystals and chalcopyrite also occur in places. The semipelitic rocks are characterized by a greater abundance of quartz and feldspar, and less biotite and other ferromagnesian minerals.

The calc-silicate rocks are finely layered on a millimetre to ten centimetre scale with alternating white, grey and pink felsic, carbonate layers and dark grey to greenish black graphitic and mafic (diopsidic) layers. Layering is believed to be of primary sedimentary origin. The calc-silicates are typically fine grained (< 1 mm) and of variable composition, comprising quartz, plagioclase, carbonate, diopside, scapolite (reported by Clarke and Fogwill, in prep), graphite, tourmaline pyrite and chalcopyrite. Clarke and Fogwill (in prep) indicate dolomite locally comprises up to 90 percent of these rocks.

In places the calc-silicates are intermixed with conformable breccia zones or layers, from a few centimetres to several metres thick. Clasts which are compositionally the same as the host calc-silicate are unsorted, typically elongate and angular to slightly rounded. In some places they are folded. The fragments are enclosed in a white to light grey, fine-grained, equigranular, finely foliated siliceous matrix containing rosettes of a pale to dark green acicular mineral which is probably actinolite.

Ray (1978, 1980) has described similar breccias within Wollaston Group calc-silicate rocks. Because of their textures and soda-rich chemistry, Ray suggested that these could be pre-metamorphic solution collapse breccias similar to those found in the Middle Devonian Prairie Evaporite of Saskatchewan.

Clarke and Fogwill (in prep.) believe the Dawn lake breccias formed by collapse into solution cavities in carbonate-rich beds exposed to pre-Athabasca weathering. However, evidence of this origin in the form of weathered hematized fragments, hematization of the cavity walls, or of foreign fragments appears lacking. A pre-metamorphic age for the breccias is indicated by the presence of metamorphic minerals in the breccia matrix.

Tourmaline-bearing granite pegmatites are pink with black tourmaline, coarse-grained (0.5 to 4 cm) quartz-potassium feldspar-plagioclase-tourmaline (schorlite) rocks. The pegmatites are generally massive but in places a foliation is developed. This foliation is defined by tourmaline-rich zones (up to 60 percent), a preferred orientation of tourmaline and a crude alignment of quartz and feldspar, particularly where older gneissose porphyroblastic granite pegmatites are cross-cut. Tourmaline commonly occurs in quartz-rich areas and sometimes contains macroscopic inclusions of quartz.

The tourmaline pegmatites are believed to have formed by anatexis of boron-rich host sediments, characteristic of sequences containing evaporites.

The Athabasca Group is normally a buff, pink, purple or grey, medium- to coarse-grained, cross-bedded sandstone and pebbly sandstone with minor pebble beds. A 5 to 10 m thick grey conglomeratic horizon occurs about 60 m above the unconformity and provides an excellent marker for determining fault movements.

Alteration

Away from mineralized areas, the typical red and green zones of the pre-Athabasca basement rock weathering profile are well developed. In the vicinity of mineralization there is a zone of intense bleaching and argillization (the crenulated zone of Clarke and Fogwill) from which the iron has been removed. This bleached zone also overprints the green zone which is reported to extend to depths of 35 m along deeply weathered pre-Athabasca faults (Clarke and Fogwill, in prep.). The base of the bleached zone coincides with the appearance of graphite, first as a few relict flakes and then in increasing concentrations to normal levels in a zone varying in width from a few centimetres to tens of centimeteres.

Altered calc-silicate rocks in the vicinity of mineralization are characterized by a fine "vugginess" and an alteration mineral assemblage comprising quartz-sericite-pyrite-graphite and chalcopyrite. Fractures and vugs are filled by euhedral quartz overgrown

successively by pyrite and chalcopyrite. Hematite staining of the quartz sometimes precedes formation of the sulphides.

Altered pegmatites commonly show feldspars with yellow and green colourations which become darker green (chloritic?) with more intense alterations. The darkest (chloritic?) alteration is accompanied in places by pitchblende and/or chalcopyrite mineralization. Although generally unaffected by alteration, the quartz is locally replaced by a soft greasy talcose material. Tourmaline has resisted both the weathering and superimposed alterations allowing even extremely altered pegmatites to be identified. Fresh-looking flake graphite is a common accessory in the altered tourmaline pegmatites.

In the vicinity of mineralization the Athabasca sandstones are intensely bleached and contain abundant clay. Staining by limonite rather than hematite is characteristic of the bleached areas. The limits of bleaching and breakdown of the sandstone are closely related to the ore zones; elsewhere the sandstone is competent, well indurated and silicified.

Mineralization

Four mineralized zones, the 11, 11A, 11B and 14 have been identified (Figs. 1 and 2). In these, uranium mineralization occurs in the Athabasca Sandstone (11 and 14), at the unconformity (11A and 14), and in the basement (11A and 11B). The following characteristics of the mineralization were noted by the writer:

1) Deep basement ore typically occurs as fracture and breccia fillings (11A and 11B) and as veins parallel to foliation (11B) in dark green chloritized rocks. Two generations of pitchblende are macroscopically visible and a third has been reported by Clark and Fogwill (in prep.). In order, these are 1) euhedral pitchblende 2) hard lustrous pitchblende and 3) medium-hard dull pitchblende. The hard lustrous variety is present along vein margins as massive aggregates and as filaments or thread-like aggregates (colloform or botryoidal pitchblende?) around cores of chlorite. Where red-brown hematitic alteration is superimposed upon the chloritic alteration, this lustrous pitchblende forms cores to the softer dull pitchblende. Nodular or amoeboid growths are typical of mineralization best developed at redox interfaces in hematized rocks. Rammelsbergite and niccolite occur in pockets of high-grade ore associated with dark green chloritization. Secondary nickel minerals (annabergite) form on ore exposed to the atmosphere.

2) Near the unconformity pitchblende is found along fractures, primarily as an earthy or sooty variety but also forming massive aggregates of lustrous pitchblende in both the bleached basement and the overlying Athabasca Group. In the Athabasca sandstones sooty pitchblende may also impregnate the wall rocks of veins coating or cementing quartz grains. In hematized clay zones in the Athabasca sandstones and also where hematization (red-brown hematite alteration) occurs in the bleached basement, nodular pitchblende growths develop across redox interfaces in both oxidized and reduced rocks. Bleached reduction haloes about the pitchblende are a common feature in some hematized ores. A petroliferous odour suggests the presence of hydrocarbon or carbonaceous material.

3. Higher up in the Athabasca Group, nodular pitchblende develops in reduction spots within the hematized rocks. It would appear that sooty pitchblende initially precipitated along fractures and then gradually permeated out along bedding planes into the adjacent porous sandstones.

Cobalt and nickel mineralizations occur in the bleached basement immediately below the unconformity and as much as 35 m above it. This mineralization usually forms a halo around the uranium mineralization rather than coinciding with it. Cobalt occurs as a black powdery amorphous mineral probably of the skutterudite series and is commonly altered to delicate pink crystallites or encrustations of erythrite. Nickel probably coexists with cobalt, but is commonly observed separately as pale green to pale blue-green annabergite stain along broken core surfaces or fractures. Arsenopyrite was observed in one drill hole.

Below the cobalt-nickel mineralization in the basement is a zone of chalcopyrite-pyrite mineralization, the latter typically occurring in veins, breccia fillings and as disseminations and overgrowths on quartz crystals in silicified calc-silicates and brecciated chloritized pegmatites. Less commonly chalcopyrite or quartz-chalcopyrite veins cut the more competent, less altered pelitic gneisses. A black coating on some chalcopyrite crystals may be a cobalt-nickel arsenide mineral. In places a halo of disseminated chalcopyrite surrounds veins of lustrous pitchblende and fragments of brecciated pitchblende veins.

Discussion

The metallogenic history of the Dawn Lake U, Co-Ni and Cu mineralization is complex. Clarke and Fogwill (in prep.) suggest that an Aphebian and/or Hudsonian syngenetic and/or metamorphic preconcentration of uranium and associated metals may have been a precursor to later unconformity-controlled mineralizations.

In the deep basement ores at Dawn Lake, pitchblende veins occur along foliation planes and are associated with strongly altered(chloritized ?) wall rocks. Similar features are observed in sub-Kombolgie Formation uranium deposits in the Alligator Rivers region of Australia (Needham and Stuart-Smith, 1980; Binns et al., 1980). Here, radiometric ages (Needham, 1981) from ore and from chlorite are coeval and point to a late tectonic (equivalent to Hudsonian) retrogressive hydrothermal event, lending some weight to the argument for a late Hudsonian metamorphic-hydrothermal origin for the deep basement ores at Dawn Lake.

Pre-Athabasca weathering is also suggested by Clarke and Fogwill (in prep.) as a possible mechanism for concentrating uranium in the basement below the zone of oxidation. Although plausible, no evidence or age dates from any Athabasca Basin uranium deposits seem to substantiate this possibility. Uranium does appear, however, to have been introduced into weathered rocks as a consequence of unconformity-related mineralizing processes.

Chalcopyrite mineralization is spatially and assumedly genetically related to the uranium mineralization. Its place in the paragenetic sequence (euhedral quartz-pyrite-chalcopyrite) is similar to that of base metal mineralization in the Rabbit Lake deposit (Hoeve and Sibbald, 1978) and the OP-zone at Cluff Lake (Harper, in prep.). It occurs only in basement rocks,in close association with the silicified calc-silicates, and in chloritized (?) tourmaline pegmatites and rims of brecciated vein pitchblende.

Acknowledgments

The co-operation and hospitality provided by Asamera Inc. is gratefully acknowledged. P.J. Clarke, R. Sproule and R. Shives are thanked for their helpful discussions and support. The views expressed herein do not necessarily reflect those of Asamera Inc.

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Uranium Metallogenic Studies: Mickey Lake Area

by D.J. Thomas

In this, the second year of a program designed to examine stratigraphic and structural relationships with respect to uranium metallogenesis in the Donaldson Lake area, a 13 km^2 area between Mickey and Hab Lakes was mapped (Fig. 1). The area is situated approximately 16 km northeast of Uranium City.

General Geology

The rock sequence exposed in the area comprises talus breccias, conglomerates and minor arkoses of the Martin Group (Fahrig, 1961; Langford, 1981), lying unconformably on a metamorphic basement regionally termed the Tazin Group (Alcock, 1936; Tremblay, 1972). The Tazin Group in the Mickey Lake area comprises a supracrustal assemblage (Fay Mine Complex, Units 1 to 4), foliated 'granitic' gneisses (Donaldson Lake Gneiss, Units 5, 6) and 'late' intrusive granites (Unit 7). Northwest-trending basic dykes intrude both Tazin and Martin rocks.

Fay Mine Complex

The Fay Mine Complex (Morton and Sassano, 1972) is represented by a mixed assemblage of supracrustal rocks within a narrow northeast-trending belt 100 to 900 m wide extending for about 3.5 km through the map area. Four distinct units are recognized: mica schist quartzite (Unit 1), quartzite (Unit 2), hornblende schist amphibolite (Unit 3) and argillite slate (Unit 4). This subdivision of the supracrustals in essence corresponds with that proposed by Tremblay (1972).

Unit 1 comprises interlayered, thinly bedded (0.5 to 3m) biotite (chlorite)-sericite-quartz schist, sericite-quartz schist and grey quartzites. It outcrops in a continuous zone extending from the north end of Mickey Lake to 500 m east of Hab Lake. A smaller area of outcrop is also observed along Long Lake. The unit lies in sharp contact with the Donaldson Lake Gneiss to the east. The mica schists are typically fine- to medium-grained (< 2 mm), grey to light brown and marked by a well-developed schistosity. The quartzite members are dark to light grey, occasionally white, fine-grained (< 1 mm) and may be massive or mylonitic. Locally, narrow bands (< 5 cm wide) of diopside-phlogopite-quartz (+ calcite) material occur interlayered with the quartzite.

Fine-grained (< 1 mm) dark grey, pale green, buff, pink and occasionally white quartzites of Unit 2 structurally overlie the interlayered mica schists and quartzites between Mickey and Hab Lakes. Irregular masses of quartzite also occur scattered throughout the granitic gneisses of Unit 6 northwest of Mickey Lake. These isolated 'islands' of quartzite generally form less than 20 percent of any outcrop (not shown on map) but locally may comprise more than 50 percent (shown on map). The quartzites are locally thinly bedded with minor mica schist, hornblende schist and argillite. Foliations are commonly cataclastic (i.e. mylonitic to ultramylonitic), although in places the quartzites appear massive. Narrow lenses and bands (1 to 20 cm) of diopside-carbonate material occur within these quartzites near their contact with hornblende schists of Unit 3.

Very fine to fine-grained, dark green to green-black hornblende schists and massive amphibolite, interlayered with minor argillite and "dirty" quartzite, outcrop immediately northwest of Mickey Lake. The contact of this unit (3) with the underlying quartzites of Unit 2 is well defined.

Unit 4 is formed by very fine grained, black to brownish black argillite and slate with minor amounts of quartzite, mica (chlorite) schist and massive epidote-chlorite rock. The contact between this unit and the hornblende schists of Unit 3 and the quartzites of Unit 2 is generally gradational over a 10 to 30 m interval. Locally, millimetre-sized angular feldspar clasts occur in argillites north of Mickey Lake and south of Hab Lake, imparting a fragmental character to the rock.

Granite and Granitic Gneiss

Two main varieties of intrusive and/or metasomatic granitoids are recognized: pre- to early syn-tectonic granitoids and late syn- to post-tectonic granites. The first variety includes the Donaldson Lake Gneiss (Unit 5) and well-foliated granitic quartzofeldspathic gneisses (Unit 6), while the latter variety comprises weakly foliated to massive leucogranites and alaskites (Unit 7).

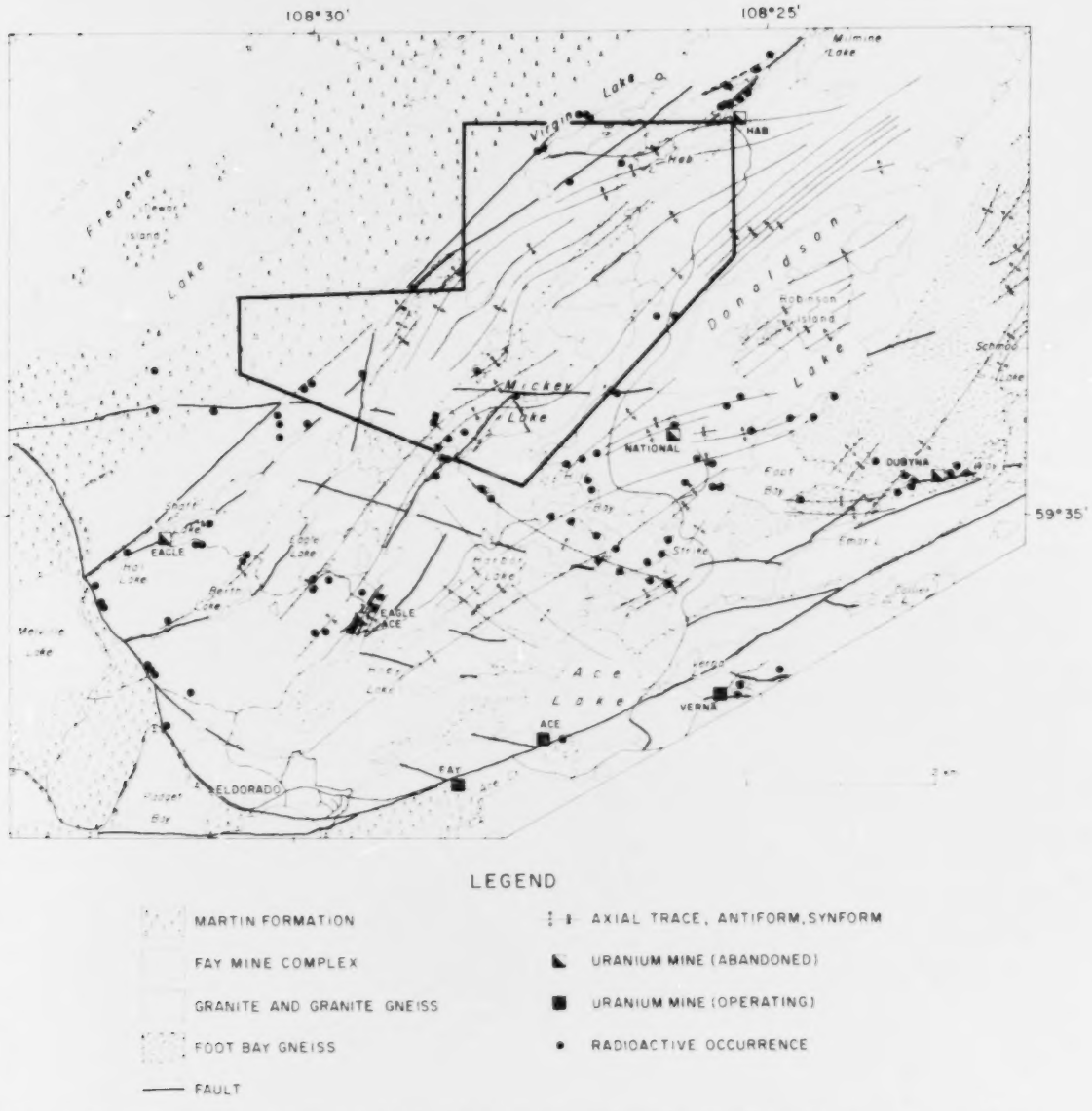

Figure 1 – Location of the Mickey Lake study area. Beaverlodge district. General geology modified from Tremblay (1972) and Sassano and Morton (1972).

Pre- to Syn-Tectonic Granitoids

The Donaldson Lake Gneiss (Unit 5) comprises a heterogeneous assemblage of granitic gneisses outcropping between Mickey Lake and Foot Bay on Donaldson Lake (east of map area). These gneisses are represented by intrusive and conceivably older basement elements. Three varieties of gneiss are recognized: biotite (± hornblende) granite gneisses, "waxy" sercite-biotite (± sillimanite) granodiorite gneiss and porphyroblastic biotite tonalite gneiss.

The biotite (± hornblende) granite gneisses are typically pink to red, fine (< 1 mm) to medium (1 to 2 mm) grained and locally feldspathoblastic (with blasts up to 1 cm in size). Colour and compositional contrasts are prominent between quartzofeldspathic and more mafic layers. Detached and boudinaged amphibolite and pyroxenite bands (< 1 m thick) generally parallel compositional banding.

'Waxy' sericite-biotite (± sillimanite) granodiorite gneisses are typically white to buff coloured, fine- to medium-grained rocks

which generally display a well-developed flasered groundmass fabric. Pale green alteration of plagioclase results in a 'waxy' lustre on fresh surfaces.

Porphyroblastic biotite tonalite gneisses form thin bands (10 to 50 m thick) particularly in the area northeast of Mickey Lake. The rock is typically buff to white when weathered and light grey on fresh surfaces. Euhedral to subhedral white feldspars (< 1.0 cm in size) are characteristic. Foliation is defined by a preferred crystallographic orientation of biotite and, locally, a weak preferred dimensional orientation of quartz and feldspar.

Granitic quartzofeldspathic gneisses (Unit 6) occupy the area northwest of the supracrustal belt extending between Mickey Lake and Hab Lake and the Martin Group rocks to the northwest. Several varieties are distinguished: gneissic and foliated (Subunit 6a), mylonitic (Subunit 6b) and brecciated (Subunit 6c). As noted the granitic quartzofeldspathic gneiss may host up to 50 percent quartzite and typically shows fabrics similar to those in the granitic gneisses.

Field relations suggest a metasomatic introduction of potassium in the genesis of these rocks. Such relations include: 1) the presence of remnants of pre-existing supracrustals, namely quartzites and locally argillites, interlayered with granite; 2) gradational textural and compositional contacts between granite and relict supracrustal material; 3) a wide variation in grain size, texture and composition between granite layers (reflecting original differences in the pre-existing supracrustal layers); and 4) the development of potassium feldspar porphyroblasts in remnants of quartzite and argillite.

Late Syn- to Post-Tectonic Granites

Massive to weakly foliated, fine-, medium- and coarse-grained leucogranites and alaskite (Unit 7) form large and small dyke-, sill- and plug-like bodies throughout the area. Contacts between these late granites and their wall rocks are generally sharp, although gradational compositional and textural relationships are observed between foliated quartzofeldspathic gneisses (Unit 6) and massive leucogranites outcropping 1500 m southwest of Hab Lake.

Martin Group

The basal conglomerate member of the Beaverlodge Formation (Langford, 1981) outcrops in the extreme northwest of the map area, as well as in several small outliers distributed along a north-trending fault north of Mickey Lake. The main rock type is a compact, red-brown, unsorted, angular talus breccia which grades upwards into sorted and locally imbricated clast- and matrix-supported conglomerates. Thin arkosic beds, generally less than 2 m thick, occur locally close to the Martin Group/ basement unconformity.

Diabase Dykes

Northwest-trending diabase dykes intrude all lithologic units northwest of Mickey Lake. Tremblay (1972) traced several of these dykes over distances of more than 1 km. The dykes are generally less than 3 m thick and are in sharp, straight contact with their wall rocks. The diabase weathers buff-brown to reddish brown and on fresh surfaces is fine-grained and dark green to green-black.

Alteration

Several types of regionally significant alteration are recognized, namely hematization, chloritization and epidotization. More localized alterations, generally associated with pitchblende veins, include carbonatization, silicification and albitization. These different types of alteration were noted to affect all rock types to varying degrees. Red hematitic alteration along seams, in veins or as a pervasive dissemination of hematite dust is most widespread. Hematization associated with uranium mineralization has produced a typically deeper red or red-brown than the lighter colour produced by the regional hematization . Chloritization is particularly widespread in the wall rocks adjacent to pitchblende veins hosted by hornblende schists and argillites, as well as in areas of brecciation and mylonitization. Epidotization, although not volumetrically important, occurs along narrow (< 2 cm) veins cross-cutting all rocks except Martin Group sediments in the area. In hornblende schists, argillites and chlorite-epidote rocks, cryptocrystalline pale green to yellow-green epidote forms irregular patches or anastomosing networks of cross-cutting veinlets. Silicification and carbonatization are particularly important in areas of uranium mineralization. Silica is generally the main gangue material of pitchblende veins occurring in felsic host rocks (i.e. granite, granite gneiss and quartzofeldspathic gneisses), whereas calcite is the prevalent gangue in mineralized veins hosted by mafic rocks (hornblende schist, amphibolite, argillite and chlorite-epidote rock). Albitization is commonly restricted to areas

of more intense deformation (i.e. adjacent to faults, as well as in brecciated and mylonitic rocks). Albitization influences the wall rocks of pitchblende veins, within zones up to 4 cm wide, at the Eagle, Hab and Dubyna deposits located adjacent to the map area (Thomas, 1981).

Structure

Original bedding (S_0) is observed in Martin Group sediments and in Fay Mine Complex supracrustals. Primary depositional structures were not recognized in the latter; therefore, tops were not determined.

Several episodes of deformation are identified. The first episode (D_1) is characterized by narrow zones of intense deformation marked by submylonitic to blastomylonitic fabrics (S_1) parallel to gross lithologic layering. In Fay Mine Complex rocks bedding is accentuated by development of subparallel gneissic banding reflecting cataclasis and metamorphic differentiation. Intervening areas of lower deformation are marked by poor to well developed schistose and gneissic foliations. Locally, the S_1 fabric appears to be axial planar to small-scale recumbent folds. This early fabric is observed in all basement rocks except late syn- to post-tectonic granites (Unit 7).

The D_2 episode is characterized by northeast-trending disharmonic upright folds with wavelengths ranging from 300 m to more than 2 km. The D_2 folding was accompanied by development of a steeply dipping axial planar fabric which appears locally as a crenulation cleavage in argillites and micaceous quartzites in the Hab Lake area. D_2 fold axes plunge gently to moderately southwest.

Poorly defined westerly to northwesterly trending D_3 folds occur in the area, but they do not appear to be accompanied by penetrative fabrics. Folds of similar orientation and probably also age are more strongly developed south of the St. Louis fault.

Several major fault sets trending east (Tom and Camdeck faults) and north (Mic fault) and minor northwest- and northeast-trending faults are recognized. The age relationship between faults is not clear; however, the east trending Tom and Camdeck Faults may be a single fault which has been offset by apparent left lateral displacement (about 600 m) along the Mic fault. All faults appear to offset D_2 and possibly D_3 folds. Fault traces are generally marked by narrow (< 1 m) zones of brecciation and the wall rocks commonly display an increase in hematization, silicification and chloritization.

Economic Geology

Uranium is the only metal commercially exploited in the immediate region, but no present- or past-producing uranium mines occur in the map area. Important past-producing mines in the vicinity include operations by Eldorado Nuclear Ltd. (Ace-Fay, Verna-Bolger, Eagle, Dubyna and Hab mines), National Explorations Ltd. and Nesbitt Labine Uranium Mines Ltd. (Fig. 1).

Uranium mineralization in the Mickey Lake area occurs principally as pitchblende fillings in veins in the brecciated wall rocks adjacent to faults and in tensional fissures related to regional folding or drag folding along major faults. It commonly occurs near but rarely within major and minor faults. In addition to pitchblende the veins may contain red hematite, pyrite, chalcopyrite, specularite, quartz, calcite, chlorite and secondary uranium minerals.

Discussion

The Beaverlodge area ranks as one of the most extensively studied regions in the Saskatchewan Shield; nevertheless, many fundamental geological questions have yet to be answered. Among these are 1) the age of the supracrustals and intervening granite terrains, 2) depositional environment of supracrustal assemblages, 3) genesis of granitic rocks, 4) relationship between structural events and granite emplacement, and 5) the tectonic environment during and subsequent to deposition of the Martin Group. Preliminary observations on the geology of the Mickey Lake area appear to show the following sequence of events:

1. Deposition of a supracrustal sequence (Fay Mine Complex) principally comprising arenaceous and argillaceous sediments, and hornblende schists, amphibolites and argillites of possible volcanic origin.

2. Intrusion of the Donaldson Lake granites, and conceivably remobilization of 'older' basement elements in the eastern part of the area with the assimilation of supracrustal rocks in the central and northern part of the map area.

3. Inhomogeneous deformation of supracrustals and granites with development of early recumbent folds (D_1) and subsequent upright northeasterly D_2 and northwesterly to westerly D_3 folding.

4. Emplacement of late syn- to post-tectonic leucogranites and alaskites.

5. Deposition of the Martin Group.

6. Extensive faulting accompanied by vein-type pitchblende mineralization in fault breccias and tensional fissures related to D_2 structures and drag folds along faults.

7. Emplacement of northwest-trending basic dykes.

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Uranium Metallogenic Studies: Gillies Channel Formation, Martin Group

by D.J. Thomas

The project comprises a geochemical and petrological study of Martin Group volcanics and sediments occurring along the east side of Martin Lake (NTS 74N-10). Samples collected belong to Tremblay's (1972) "Lower Arkose" and "Basalt-Andesite" members which have recently been renamed the Gillies Channel Formation (Langford, 1981).

The purpose of the study is to determine:

1) the petrographic and chemical characteristics of the volcanics, and thence establish their possible eruptive environment;

2) the nature of any subsequent alteration events and their relation to vein-type pitchblende mineralization;

3) the distribution pattern of trace metals through the succession.

Sample sites were selected from Tremblay's (1972) 1:14,400 scale geological map of the Beaverlodge area. Samples were collected across strike on lines spaced 150 to 300 m apart. A suite of 43 volcanics and 24 sediments was obtained, of which 20 volcanics and 15 sediments will be analyzed for major elements and the whole suite for the following trace elements: Rb, Sr, Y, Zr, Nb, Ag, Cd, Co, Cu, Mn, Mo, Pb, Ni, Zn, Cr, As, Sb, Au, W, Th, B, Bi, La, V, Ba, K, Mg, P, Ti, U, Th.

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Uranium Metallogenic Studies: Relationship Between Hudsonian Soda Metasomatism and Beaverlodge Vein-Type Uranium Mineralization

by J. Hoeve[1]

To date this study has involved a review of existing data and opinions relating to soda metasomatism in the Beaverlodge area (Hoeve, 1982) and a field sampling program. In the following, the main points emanating from the literature review are summarized together with details of the sampling program.

General Review

Uranium occurrences at Beaverlodge have traditionally been divided into syngenetic and epigenetic types, the former being represented by uraninite in pegmatites and the latter by a variety of pitchblende vein-type deposits, with simple and complex parageneses. Deposits with a simple paragenesis are dominated by pitchblende, whereas those with a complex paragenesis contain, in addition, a broad suite of associated minerals including Ni-Co arsenides, selenides and sulphides.

Previous discussions on the classification and origin of the mineralization have treated the deposits of simple and complex mineralogy as belonging to one and the same category. At one time they were considered as prime examples of classical magmatic-hydrothermal deposits (Edie, 1951; Ridge, 1958; Maucher, 1962), an opinion which was largely inspired by the U-Ni-Co-As assemblage displayed by some of the deposits. Ironically, this same element suite was later taken as evidence of a near-surface supergene origin (Langford, 1977). Other authors, with more intimate knowledge of the geology of the area and the setting of the deposits, advocated a metamorphic-hydrothermal origin connected with Hudsonian orogenesis (Beck, 1969; Tremblay, 1972). Likewise, the syngenetic pegmatitic occurrences were interpreted as of Hudsonian metamorphic origin. Beck (1969) actually favoured a continuum between syngenetic uraninite and epigenetic pitchblende mineralization.

Advances in concepts of the geological evolution in northern Saskatchewan led Hoeve(1978) and Hoeve and Sibbald (1978) to propose for the Beaverlodge district that the deposits of simple and complex mineralogy are not cogenetic but manifestations of entirely different episodes of metallogenesis. Based upon a correlation between deposit type (simple versus complex) and age, they argued that the deposits of simple mineralogy were formed 1740 Ma ago and are of Hudsonian metamorphic-hydrothermal origin, whereas those of complex mineralogy were formed during Koeppels's (1968) first remobilization episode at 1100 Ma and may be equated with the unconformity-type deposits of diagenetic-hydrothermal origin in the Athabasca Basin. Significantly, deposits of simple mineralogy are hosted by basement rocks, whereas those of complex mineralogy are hosted by both the basement and the overlying Martin Formation.

This interpretation received support in a geochronological review by Bell (1981). It appears that uranium mineralization at Beaverlodge is relevant to an understanding of the overall geological and metallogenic evolution of northern Saskatchewan and that present aspects of the mineralization reflect multiple episodes of metallogenesis.

More recently, the author (Hoeve, 1982) argued that the vein deposits of simple mineralogy are related to widespread soda metasomatism, accompanying the peak of Hudsonian metamorphism and magmatism at 1740 Ma, and that the mineralization may belong to the world-wide Na-U-Ti class of metamorphic-hydrothermal deposits.

Albitization of wallrocks is an important characteristic of the veins of simple mineralogy, and is a feature often mentioned by the earlier workers in the district (Beavon,1938; Christie, 1953; Robinson, 1955; Dawson, 1956), as opposed to later authors who give it little or no attention (Beck, 1969, Tremblay, 1972). Yet albitization appears to be more widespread and more characteristic of mineralization than has been hitherto recognized. At the Ace-Verna mine (Christie, 1953; Robinson, 1955) mineralization is emplaced in fractured "red mylonite", which actually consists of fine-grained albitite or quartz albitite. Dawson (1956), in his petrographic description of red altered wallrocks, frequently mentions albitization of varying intensity accompanying hematitization. At the Gunnar deposit, often considered enigmatic and erroneously compared to the French episyenites (Munday, 1978; Nash et al., 1981), mineralization is hosted by

[1] Saskatchewan Research Council. Also recorded as SRC Publication No. G-745-6-A-82.

albitized granite, referred to as "syenite" (Evoy, 1961). Beavon (1938) and Christie (1953) describe albitization of the Athona and Box granites in association with gold mineralization.

More general soda metasomatism can be inferred from Beck's (1969) published granite analyses which show some bodies to be almost pure quartz albitites. Both of Beck's granite generations (older and younger granites) are affected, (Beck, 1969; analyses 13, 5, 11, 18).

The behaviour of other elements during soda metasomatism can be tentatively inferred from the few published analyses of albitized granite and of albitized wallrocks of veins (Dawson, 1956; Beck, 1969). It is as follows: inert-Al_2O_3; lost-SiO_2, TiO_2, ΣFe_2O_3, MgO, K_2O, H_2O, P_2O_5 and a broad suite of trace elements; gained-Na_2O and CaO. It seems that soda metasomatism was essentially a leaching process in which a broad suite of major and trace elements was extracted from the affected country rocks and replaced by introduced sodium and calcium.

The above relationships suggest an intimate connection between widespread soda metasomatism and pitchblende mineralization, a connection which at least at an empirical level, has already been recognized by earlier workers. According to Robinson (1955), who gave a generalized cumulative paragenetic scheme for the epigenetic uranium mineralization in the area, first stage pitchblende mineralization was preceded by a phase of albitization. Subsequent brecciation in the albitites created the open spaces in which pitchblende was precipitated. Since some of the pitchblende veins contain albite as a gangue mineral, albitization and mineralization seem to have partially overlapped, suggesting that they may represent different manifestations of an evolving hydrothermal system.

Present Work

During the summer of 1982 the Saskatchewan Research Council in cooperation with the Saskatchewan Geological Survey mounted a sampling program to provide material for mineralogical and geochemical studies of host rock alteration at Beaverlodge. About 100 samples were collected, covering a dozen host rock alteration sequences associated with veins of simple and complex mineralogy; in addition a few samples were taken from albitized granitic rocks not directly associated with known mineral occurrences.

The objectives of these studies are to identify diagnostic criteria for differentiating between host rock alteration connected with the two types of mineralization, and to assess the role of Hudsonian soda metasomatism in epigenetic uranium mineralization.

Budgetary restrictions have to date prevented commencement of the analytical program.

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Uranium Metallogenic Studies: New Developments in SRC's Lithogeochemistry Program

by Michel Mellinger[1]

The Saskatchewan Research Council's Lithogeochemistry Program emphasizes the development of expertise in basic methodology and the application of lithogeochemistry to mineral exploration.

Developments in this area were summarized in a two-day seminar in the winter of 1982, which was attended by company and government geologists (Mellinger, 1982a, b). Also, reports are in preparation that will cover specific applications and new developments in the analysis of lithogeochemical data.

Two new developments are briefly presented here. The first is the definition of a data file format for lithogeochemical data, which was carried out with the financial support of Saskatchewan Energy and Mines. The second is the design of a computer system for the interpretation of lithogeochemical data, and is part of SRC's core Lithogeochemistry Program.

The Lithogeochemistry Data File

A report describing in detail the format and use of the Lithogeochemistry Data File (LDF) is in preparation and will be published shortly. The purpose of LDF is to provide a computer-based standard data file structure for the coding, storage and retrieval of lithogeochemical data and complementary information relevant to the interpretation of the data. The LDF was designed to satisfy two usually contradictory criteria: (1) be exhaustive enough to include all relevant information, and (2) be sufficiently compact to allow easy manipulation and usage. This was achieved through a dual structure comprising a Header File and a Master File (Fig. 1a).

This data file is compatible with the Geochemical Data File which is used mainly for surface geochemical data at the Saskatchewan Geological Survey (Dunn, 1978).

The Header File can be used as an index and a catalog, and contains general information about each sample. This information is seldom used directly in the analysis and interpretation of the data, but helps to characterize surveys and select appropriate sets of samples for detailed study. The file consists of one 80-column record per sample (Fig. 1b) and includes sample number (short form), field sample number (extended form), NTS sheet number, UTM zone and coordinates, sample medium, analytical laboratory labels, information related to the Master File records for the sample, type of non-geochemical work carried out on the sample, and card-type identifier (= 99).

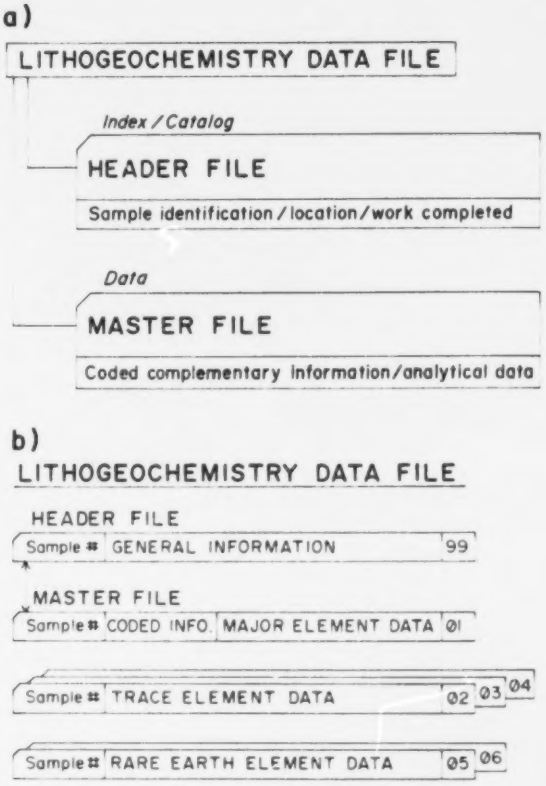

Figure 1 – a) the dual structure of the Lithogeochemistry Data File; b) the internal structure of the Lithogeochemistry Data File.

The connection between records from the Header File and the Master File is achieved by the sample number (short form).

The Master File contains the data and coded complementary information directly relevant to the analysis and interpretation of the data.

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[1]Saskatchewan Research Council; activity reported here received some financial support from the Saskatchewan Geological Survey. Also recorded as SRC Publication No. G-740-11-D-82.

This part of the file is used for data analysis and interpretation work. This file consists of several 80-column records for each sample (Fig. 1b), and includes:

(1) record-type 01: sample number (shortform), location codes (X,Y,Z, flag), stratigraphic codes (unit, sub-unit), petrographic codes (rock type, metamorphic grade, texture, petrographic facies), major element analytical data (12 pre-defined fields), and card-type identifier (= 01).

The location and stratigraphic codes are essentially project-dependent. The petrographic codes are essentially pre-defined, following nomenclatures from Folk (1974) for sedimentary rocks, Streckeisen (1976) for igneous rocks, and Williams et al. (1954) and Gilboy and Ray (unpublished) for metamorphic rocks. A hierarchy for the various codes is defined that allows compact coding of the complementary information.

(2) record-type 02 to 04: each record starts with the sample number (short form) and

Table 1. Comparison of characteristics of a mainframe computer and a graphics microcomputer.

Mainframe Computer	Graphics Microcomputer
Hardware:	
(*) large memory space (eventually virtual)	- limited memory space
(*) large data storage available	- large data storage possible
(*) high processing speed	- low processing speed
System Design:	
- multi-purpose processing and outputs	(*) specialized graphic outputs
Software:	
- mostly available on the market	- mostly developed by user
Status of User:	
- customer of the computer center	- owner/renter
Cost to User:	
- no direct acquisition cost (hardware)	- acquisition cost (hardware)
- software cost variable	- high software cost (mainly in man-years)
- high operating cost, rates based on system usage (CPU, connect, storage, I/O, ...)	(*) low operating cost

Notes: (*) indicates which characteristics of each computer environment were determinant in the design of the computer system shown in Figure 2.

CPU = central processing unit (core memory), I/O = input/out operations and devices.

ends with the card-type identifier (= 02, 03, 04), and contains trace element data excluding rare earth elements. Seventeen fields are pre-defined for trace elements on each of the 02 and 03 records. The 04 record is open for additions as required.

(3) record-type 05 and 06: each record starts with the sample number (short form) and ends with the card-type identifier (= 05, 06), and contains rare earth element (REE) data. Eight fields are pre-defined for those REE data that are easily analyzed by neutron activation; other fields are open for additional REE data. The 05 record contains raw REE data, whereas the 06 record contains the chondrite-normalized REE data (a short FORTRAN program is available for the 05 and 06 conversion).

(4) other record-types: additional record-types will probably not be required for geochemical data for some time, as the existing record-types accommodate many combinations of common analytical data requests. Card-type identifiers 91 and 92 are presently used at SRC for the coding of X-ray diffraction clay mineral data.

Design of a Computer Environment Adapted to Geochemical Investigations

Generally, computer systems must be designed to suit particular applications under given

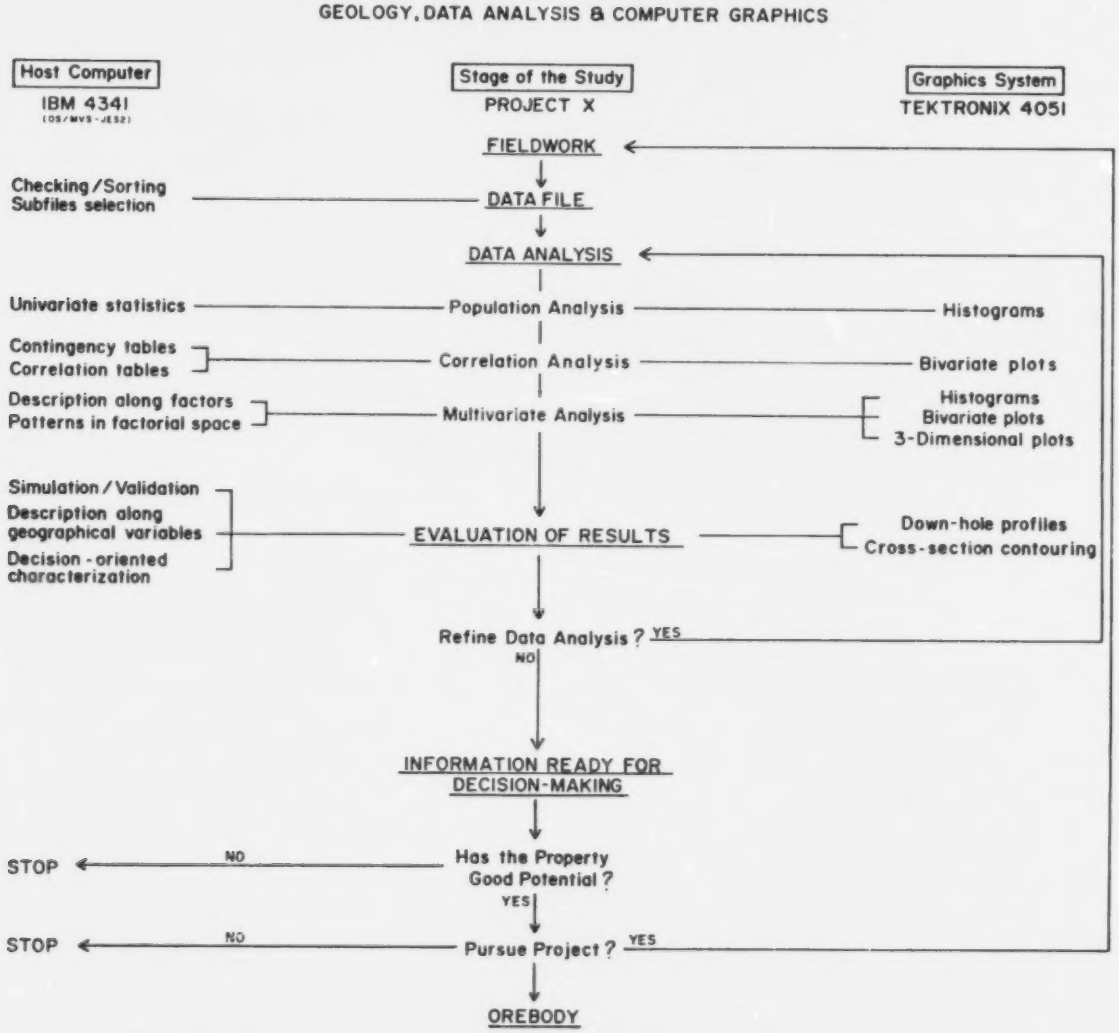

Figure 2—A computer environment adapted to lithogeochemical investigations, applied to mineral exploration.

operational constraints. The basic problem here is to establish a computer system that allows: (1) effective data analysis making extensive use of multivariate techniques (such as factor analysis, hierarchical classification), and (2) user-interactive graphical analysis and visualization of the data and results from data analysis. Many organizations facing the same basic problem have solved it by implementing both of the above functions in the same mainframe computer environment, because of the easy accessibility of such an environment. An alternate approach involves two different computer supports, each of which is specifically adapted to each of the two functions mentioned above: multivariate data analysis and graphical analysis (Table 1).

The general framework adopted in this alternative approach is shown in Fig. 2. The centre column of the diagram is a flow-chart of a typical lithogeochemical study, starting with fieldwork and ending with decision-making, and to each side are shown the tasks performed by each computer system. To the left is shown the computer support provided by a mainframe environment (IBM 4341 in our case), which handles large computations and the creation of output files at the various stages of the study. To the right is shown the computer support provided by a stand-alone local work station specialized in graphics (TEKTRONIX 4050 series in our case), which allows the user to examine, interactively and in a flexible way, the data files created in the mainframe environment (raw data, factor coordinates, etc.). Electronic communication channels and procedures are required and include: (1) direct-line access to the mainframe computer to carry out data analysis; (2) direct-line link between the mainframe computer and the graphics work station for data file transfer; (3) the use on the mainframe computer of a standard data file format (the LDF format; see above) and of standard editing procedures prior to data file transfer to the graphics work station; and (4) the use of standard re-formatting and editing procedures for data files at the graphics work station, prior to graphical analysis.

This approach answers operational constraints experienced by many companies and organizations by taking advantage, at the same time, of the power offered by a mainframe computer, and of the specialized nature and low operating cost of the graphics work station (Table 1). Recent developments in microcomputer technology and software will make such an approach attractive to more users by offering them more flexibility and easier interaction with their data at an overall lower direct cost.

Acknowledgements

The Saskatchewan Geological Survey is gratefully acknowledged for financial support of the Lithogeochemistry Data File project during the year 1980-81; several people from the Saskatchewan Geological Survey helped improve an earlier version of the coding scheme, and are acknowledged here collectively for their cooperation.

The implementation of a system for the analysis and visualization of lithogeochemical data would not be possible without the help of J.W.J. (Bill) Smith, whose constant cooperation is greatly appreciated.

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Gold Metallogenic Studies: Amisk Lake East Area

by J.G. Pearson

In this, the fourth and final year of gold metallogenic studies in the Flin Flon region, five gold occurrences were examined in the Amisk Lake East area: Robinson Creek, Mitchell, Sye, Amisk Syndicate and Mosher Lake (Figure 1).

The occurrences were geologically mapped in detail, unaltered and altered lithogies were sampled for geochemical and petrographic studies and channel samples were obtained from the mineralized zones.

The area has been previously mapped by Wright (1932), Byers and Dahlstrom (1954) and MacDougall et al. (1979).

General Geology

The Amisk Lake East area consists of a complexly folded sequence of submarine volcanic rocks, ranging in composition from tholeiitic basalt to rhyolite, mafic to acid fragmental rocks and volcanogenic sediments of the Amisk Group, unconformably overlain by conglomerate and greywacke of the Missi Group. Both Groups have been intruded by mafic to ultramafic dykes and sills, and by the Reynard Lake pluton.

They are folded about northwesterly trending axial planes and cut by northwesterly trending faults coeval with these folds.

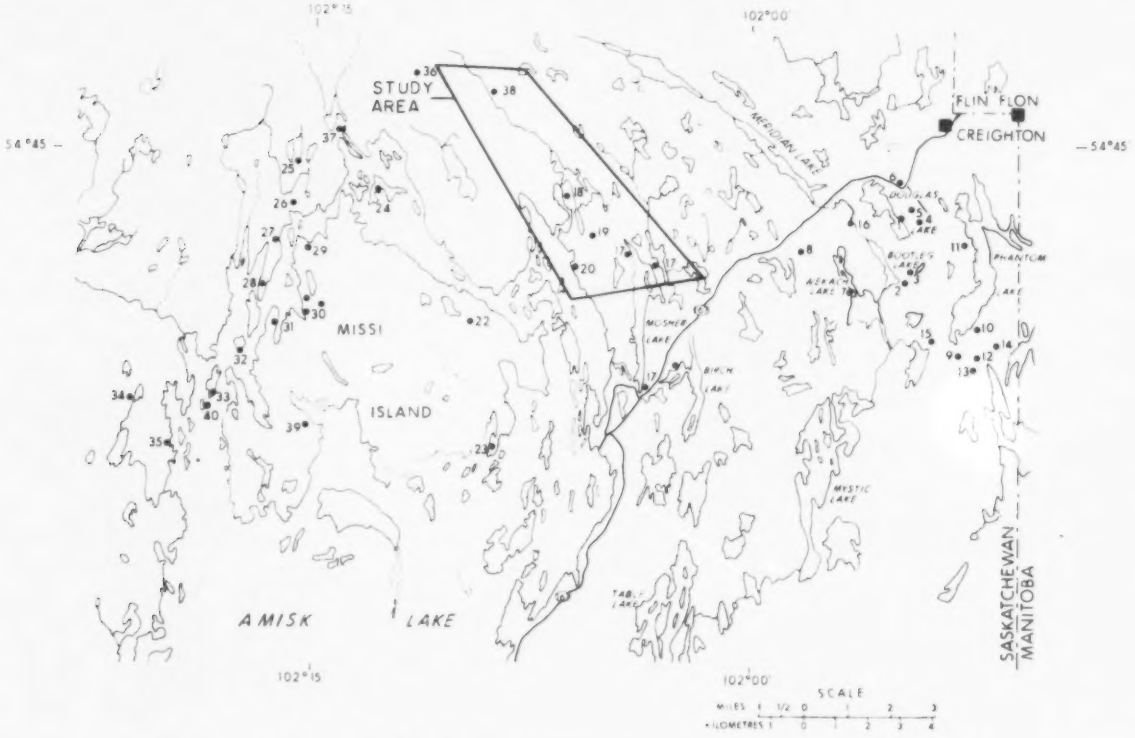


Figure 1—Gold occurrences in the Flin Flin—Amisk Lake area: 1, Newcor Mine; 2, Henning-Maloney Mine; 3, Rio; 4, Unity; 5, Cor; 6, Bomber Lake; 7, Wekach Lake; 8, Angelski; 9, Phantom Lake Mine; 10, MacMillan Mine; 11, North Phantom Lake; 12, Yellow Jacket Group; 13, Phantom-McRobbie Lake; 14, Dee Claims; 15, Boot Lake; 16, Dodo; 17a, Mosher Lake East; 17b, Mosher Lake North; 17c, Mosher Lake South; 18, Mitchell; 19, Sye; 20, Amisk Syndicate; 21, V.M. Group; 22, Derby (Hoodo); 23, Lucky Strike; 24, Royal; 25, Kent; 26, Duplex; 27, Monarch Mine; 28, Amisk Gold Syndicate; 29, T.C.A.; 30, Laurel; 31, Beaver; 32, Hannay Island; 33, Waverly Island; 34, Wing; 35, Bud; 36, Graham Mine; 37, Golden Cross; 38, Robinson Creek; 39, Ace; 40, Sonora.

Description of Gold Occurrences

Amisk Syndicate

The Amisk Syndicate occurrence (Figures 1 and 2) is underlain by a sequence of basalts and pillowed dacite flows intruded by discordant gabbro bodies. The basalts, which are intensely carbonatized, outcrop throughout the peninsula. They are dark green when weathered and grey-green on fresh surfaces, fine grained and commonly show a well-developed cleavage. Varying degrees of carbonatization by ankerite and/or calcite influence the basalts, and in places complete alteration yields an ankeritic rock. At the north end of the peninsula the basalts are intruded by narrow (1 to 6 cm wide) quartz veins, which in turn are cut by narrow carbonatized faults trending 140 to 160°, dipping 75° E and showing right-laterial movement. Although the movement on any single fault is small, the cumulative movement across an outcrop may be several metres. The quartz veins are drag folded on vertically plunging axes into the faults. In one area the faults are folded and plunge 70° to the north.

Pillowed dacite flows outcrop at the south end of the peninsula. They weather light olive green, are grey-green on fresh surfaces and comprise 75 percent plagioclase phenocrysts up to 2 mm in diameter.

Massive, medium-grained, greenish-grey gabbro with varying amounts of calcite forms slightly discordant bodies in the central part of the peninsula.

Three types of alteration, namely carbonatization, silicification and, in the area of some of the quartz veins, tourmalinization, influence all rock types.

Carbonatization, marked by the introduction of calcite and/or ankerite, is the dominant type of alteration. In the northern part of the peninsula, ankerite constitutes a minor amount of bedrock, whereas in the central part there is massive replacement. Some of the quartz veins which cut this intensely ankeritized rock contain tourmaline.

In the southern and eastern part of the peninsula dacitic pillow lavas and basalts are altered to a calcite breccia which locally approaches a marble in composition. In areas of basalt calcitization, relict fragments of basalt, commonly less than 1 cm in diameter, are surrounded by recessively weathering networks of calcite veinlets typically 1 cm or more in width.

In the south and southwest parts of the peninsula the calcite breccia contains up to 5

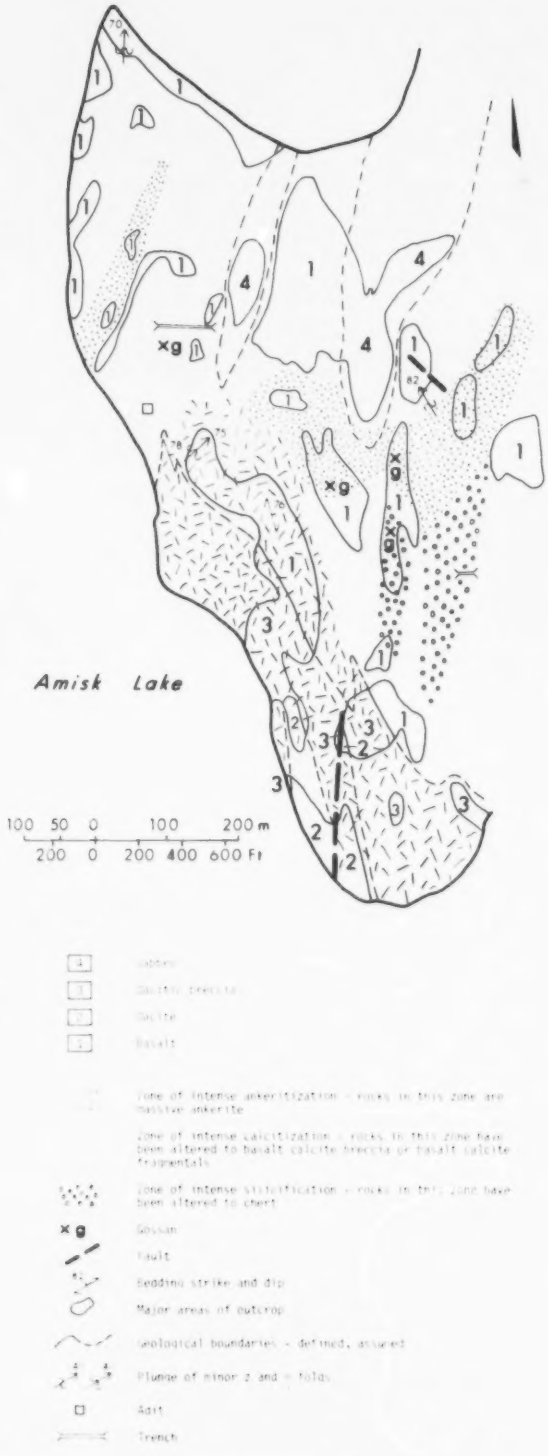

Amisk Lake
100 50 0 100 200 m
200 0 200 400 600 Ft
Gabbro
Dacitic breccia
Dacite
Basalt
Zone of intense ankeritization - rocks in this zone are massive ankerite
Zone of intense calcitization - rocks in this zone have been altered to basalt calcite breccia or basalt calcite fragmentals
Zone of intense silicification - rocks in this zone have been altered to chert
Gossan
Fault
Bedding strike and dip
Major areas of outcrop
Geological boundaries - defined, assumed
Plunge of minor Z and F folds
Adit
Trench

Figure 2 – Geological sketch map of the Amisk Syndicate gold occurrence.

percent rounded dacitic fragments (up to 30 cm long). It is uncertain, in this case, whether the breccia derives from dacitic flows or fragmental rocks.

The calcite breccias are crosscut by occasional thin (2 to 4 mm) bands of finely laminated tuff (?) which are crenulated by small folds plunging 75° to the northeast, but which show no evidence of brittle fracture.

In the eastern part of the peninsula silicification, apparently related to carbonitization, variably influences the basalts and in places these become altered to chert.

Two zones on the peninsula are reported to contain gold mineralization. On the west side, a 35 m long adit and some trenches cut several narrow north-trending quartz veins. This zone is poorly exposed but the host rocks appear to be sheared, carbonatized and silicified basalts. The quartz veins contain pyrite and arsenopyrite in disseminations and in veinlets, and also some tourmaline. The gossan associated with the zone pans several colours of flour gold.

A zone on the east side of the peninsula, exposed in one large trench, is hosted by silicified basalt. Zones containing up to 10 percent disseminated pyrite parallel the intense cleavage that has developed in the silicified rocks. The gossan associated with this zone does not pan gold.

Mitchell

The Mitchell occurrence lies on a height of land between Wolverine Bay, Amisk Lake and Wolverine Lake. The peninsula is underlain by Amisk Group massive basalt, plagioclase-phyric basalt and gabbro, Missi Group conglomerate and a conformable porphyritic granodiorite related to the Reynard Lake pluton (Figure 3).

The massive and plagioclase-phyric basalts are dark green and very fine grained, the latter containing randomly oriented plagioclase laths up to 1 cm long. In some areas, well-developed flow top breccia and interflow hyaloclastite are present. The two, apparently interfingering, flow types are commonly pillowed and, in the western part of the peninsula, a normal westerly sequence is indicated.

The Missi Group is represented by a poorly sorted clast-supported conglomerate containing cobbles (from 3 to 25 cm in size) of granite, granodiorite, gabbro, feldspar and quartz porphyry, massive and amygdaloidal basalt, tuff and oxide facies iron formation.

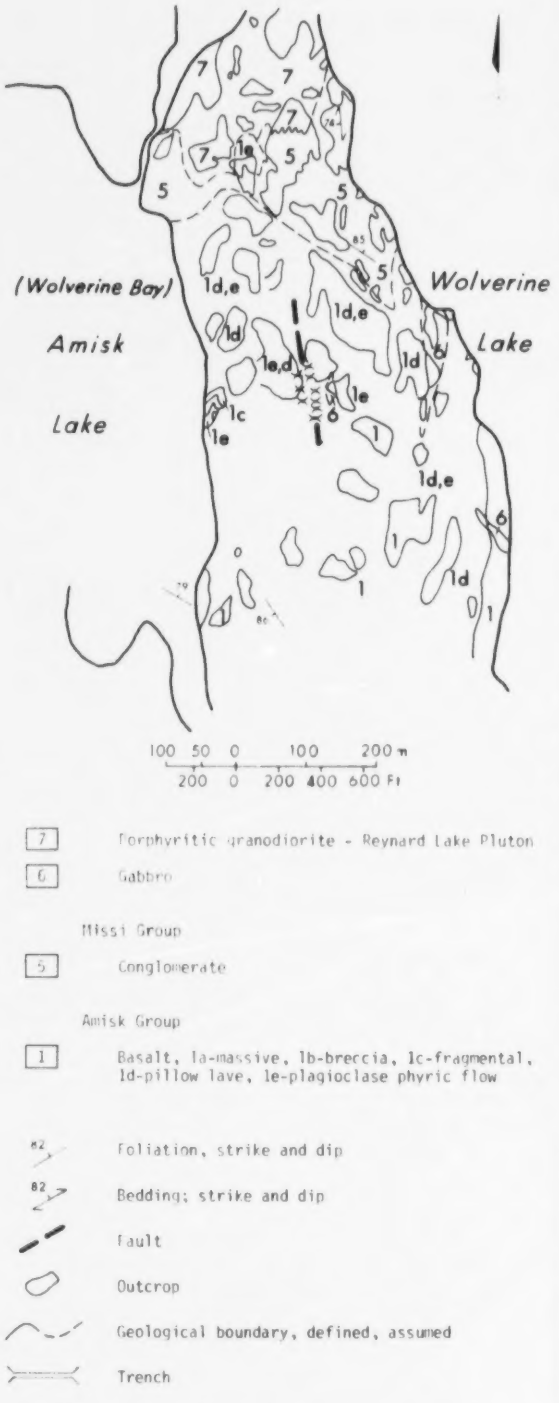


Figure 3 – Geological sketch map of the Mitchell gold occurrence.

The cobbles, which make up 80 percent of the rock, are set in a sand-sized greenish-grey greywacke matrix which also forms rare sandy lenses. The conglomerate is tightly folded; however, because of the varying competence, the deformed shapes of the different clasts are irregular with length to width ratios ranging from 1:1 for granite cobbles to 30:1 for some basalt cobbles.

The porphyritic granodiorite is pink, medium grained and may comprise as much as 30 percent feldspar phenocrysts up to 7.5 mm long set in a quartz-feldspar matrix. It is marginally foliated, parallel to the folded contact with the Missi conglomerate. Thin (5 cm), conformable, barren quartz veins occur in the granodiorite.

Alteration is marked by pervasive ankeritization which affects the basalts only, up to 30 percent of the rock in some places. Small (20 cm wide) veins of massive ankerite which in some areas have small quarts ladder veins outcrop along the west shore. Both the ankerite and the quartz veins are barren.

The Mitchell occurrence lies in two parallel zones in the poorly exposed central part of the peninsula. One zone is developed by six trenches, over a length of 120 m and the other by three trenches. The zones comprise strongly carbonatized, sericitized and silicified basalt, which hosts quartz and quartz-ankerite veins from 2 to 50 cm wide within an alteration envelope about 5 m wide. Mineralization consists of disseminated pyrite, rare chalcopyrite and malachite; in addition, Byers and Dahlstrom (1954) reported the presence of arsenopyrite and tourmaline. A few colours of flour gold can be panned from this occurrence. The zones appear along fractures which parallel the axial planes of the northerly trending folds which deform the contacts of the different rock units.

Mosher Lake

There are three occurrences in the area of Mosher Lake of which two (the Mosher East and Mosher North) were examined.

The Mosher East occurrence is in a sequence of northwesterly trending basalts, gabbros and rhyolites which are cut by a northeasterly trending fault showing about 300 m of dextral movement (Figure 4).

The basalts are typical of those in the area, being dark green, fine grained and showing a variety of volcanic features including pillows, amygdules and interflow tuffaceous lenses. Some of the flows are plagioclase-phyric.

The acid volcanics are light green to white massive flows (welded tuff?), laminated tuffs and pyroclastics.

The gabbro is massive and medium grained and consists essentially of plagioclase (60 percent) and amphibole (40 percent).

The basalts are cut by small northeasterly trending quartz-carbonate-filled fractures, which dip steeply to the northwest and show a

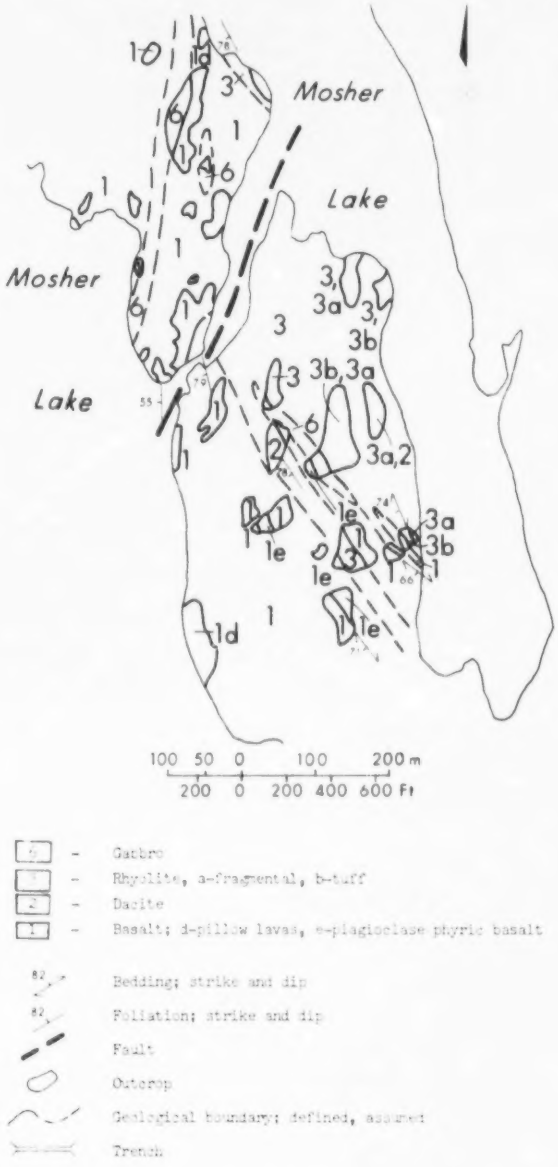
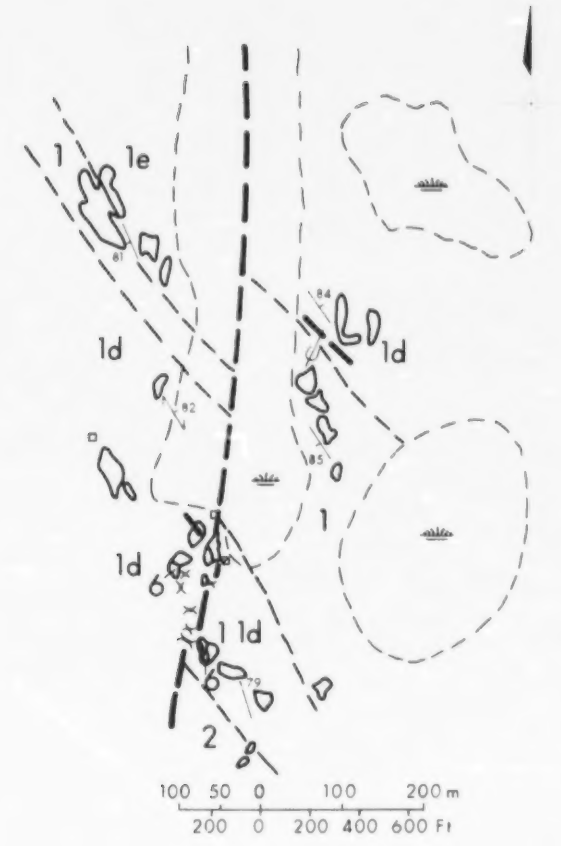


Figure 4—Geological sketch map of the Mosher Lake East gold occurrence.



6 - Gabbro
2 - Volcanogenic sediments
1e - Plagioclase phyric basalt
1d - Pillow basalt
1 - Massive basalt

82 Foliation strike and dip
82 Bedding strike and dip
Glacial striation
Outcrop
Fault
Geological boundary - defined, assumed
Trench
Shaft
Cabin

Figure 5 – Geological sketch map of the Sye gold occurrence.

small amount of dextral movement. The fractures parallel the small channel between the two arms of Mosher Lake.

The gold occurrence reported by Wright (1932) is immediately north of this channel and is represented by a trench cutting two of the fractures. The fracture filling comprises around 80 percent massive white quartz, 10 percent ankerite and 10 percent wall rock fragments, together with some small blebs of chlorite and minor pyrite. The wall rock is a silicified basalt which contains small amounts of ankerite, muscovite and biotite. No gold could be panned at this location. The quartz-carbonate-filled fractures appear to be tension fractures related to the faulting.

Bedrock in the area of the Mosher north occurrence consists of mafic flows, pillow lavas, narrow gabbro bodies and massive rhyolite (welded tuff?). Deformation and alteration associated with the Mosher Lake Fault has given rise to a vuggy carbonatized rusty weathering breccia containing small angular chert-like fragments and disseminated and massive pyrite. Adjacent to this alteration are narrow zones of massive pyrrhotite and pyrite which can be traced along strike for some 200 m. Gold content of these zones is not known; however, no gold could be panned from the trenches.

Sye Occurrence

The rocks in the area of the Sye occurrence (Figure 5) form a westerly-facing sequence of basalt flows, flow top breccias, interflow hyaloclastite, thin discontinuous gabbro dykes and volcanogenic sedimentary rocks. The basalts are variously massive, pillowed, non-phyric and plagioclase- and pyroxene (hornblende)-phyric. In the northern part of the map area both phyric and non-phyric flows show a well-developed subvertical cleavage which parallels bedding and trends 150°.

The volcanogenic sediments are massive greenish-brown rocks containing small feldspar phenocrysts and narrow (5 cm wide) lenses of laminated boudinaged siltstone.

Two parallel fracture zones show evidence of mineralization. The easterly zone has been evaluated through a 7 m deep shaft and five trenches over a strike length of about 125 m; however, only the trench associated with the shaft exposes the mineralized zone. It is northerly trending and consists of a number of anastomosing quartz-ankerite veins, 1 to 20 cm in width, which comprise about 40 percent of bedrock over a width of about 1.6 m. The wall rock is carbonatized and

silicified, and some sericite is developed on parting surfaces. The mineralization is represented by irregular blebs and veinlets of pyrite in the quartz-ankerite veins, and gold. Gold is found as small blebs (up to 1 mm across) on the edges of the quartz veins. Byers and Dahlstrom (1954) also reported the presence of arsenopyrite.

The second zone occurs 20 m to the west of the shaft zone. It also comprises narrow quartz veins in sheared carbonatized and silicified basalt, both of which contain disseminated pyrite.

The gossans above both zones pan a few colours of flour gold.

Robinson Creek

In the Robinson Creek area (see accompanying map) three occurrences, called the Quartz, Vein and Bleiler Zones, have been identified. All of these pan gold. The area is underlain by massive basalt of the Amisk Group, greywacke and conglomerate of the Missi Group and porphyritic granodiorite of the Reynard Lake pluton.

The basalt is commonly massive, foliated and fine grained. Plagioclase-phyric flows are present locally, as are small fragmental zones. Volcanic structures and textures are generally lacking.

Missi conglomerate and greywacke occur on the north and west sides of the map area. The conglomerate contains granitoid, gabbroic, basaltic, tuffaceous and iron formation cobbles in a greywacke matrix. In places, especially around the Quartz zone, the cobbles are strongly deformed with length ratios ranging to 30:1. The greywacke is grey, medium grained and contains volcanic and sedimentary clasts. It appears well laminated because of recessively weathering ankerite layers.

The granodiorite is a pink, medium-grained porphyritic rock with small salmon pink feldspar phenocrysts up to 4 mm long. It is typically well foliated with ankerite occurring in areas where the foliation is most strongly developed.

The area is structurally complex; the supracrustal rocks occupy the nose of a northwesterly plunging antiform enveloped by granodiorite of the Reynard Lake pluton. Angular unconformity between the Amisk and Missi Groups and discordant dyke and sill intrusions of the Reynard Lake granodiorite complicate geometric relationships as do subsequent deformation events.

The Quartz Zone in the northwest part of the property consists of a wide zone of quartz-carbonate veining, stratabound within the greywacke. The veins, which individually are less than 20 cm across, comprise up to 70 percent of bedrock over widths of up to 30 m. The conglomerate, greywacke and accompanying mineralization occupy a northwesterly plunging fold keel in the granodiorite. Some veins, remobilized during the main period of folding, are axial planar to the folded primary veins. These typically contain some feldspar. A few percent pyrite, minor chalcopyrite and arsenopyrite are present in the veins. Host rock alteration includes carbonatization and silicification. Sericite is developed on partings and tourmaline is found in association with the quartz-ankerite veins.

The Vein Zone is located in the southeast part of the property and consists of two parallel zones of steep southwesterly dipping quartz veins up to 1 m wide separated by 9 m of basalt, and traceable for about 100 m.

The vein quartz is white, fine grained, and contains pyrite, arsenopyrite and chalcopyrite (Byers and Dahlstrom, 1954). The host rock is massive, silicified and carbonatized basalt.

The Bleiler Zone is in the northeast part of the property and is exposed in only one trench. It consists of a 2 m wide zone of narrow, very fine grained, chert-like quartz veins in foliated, silicified basalt. The mineralization comprises disseminated pyrite in the quartz veins and altered basalt.

Conclusions

Although the gold occurrences in the Amisk Lake East area are in different rock types they have many common features. Most are associated with northwesterly trending quartz-carbonate veins surrounded by alteration comprising carbonatization, silicification and tourmalinization. If typical, relationships observed in the Robinson Creek area indicate that the mineralized veins were emplaced prior to, or contemporaneously with the Reynard Lake pluton. The area was then deformed by folding about northwesterly trending axial surfaces and by coeval faulting parallel to these axial surfaces. The folded veins were remobilized in these northwesterly trending axial fracture zones.

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Base Metal Studies: Dianne Lake Property

by B. P. Scott

The Dianne Lake project is located approximately 15 km northwest of Uranium City. The showings are located 0.5 km east of the east bay of Garry Lake.

The surrounding region was geologically mapped by W.E. Hale (1953) at a scale of 1:63,360.

In June of 1968, prospectors Frank Buller and Art Sjolander discovered low-grade copper near Dianne Lake while prospecting for Consolidated Skeena Ltd. Later work revealed native silver. In the following 12-month program, the area immediately surrounding Doug Lake and Dianne Lake was geologically mapped at a scale of 1:1200. Ten trenches were cut and sampled across the copper zone at Doug Lake and seven pits were dug on the silver zone near Dianne Lake. In addition soil geochemistry, IP, magnetometer and low and high frequency EM surveys were carried out, and followed up with a 6800 m 50-hole drill program (Kennedy, 1980).

The present work consisted of:

a) geological mapping along section lines spaced 31 m apart;

b) rock chip sampling at 31 m intervals along section lines, for future geochemical work;

c) detailed mapping in trenches and pits of the Dianne Lake zone; and

d) geological mapping of an area lying between the Charlot River and latitude 59° 43' N, and between longitudes 108° 45' and 108° 55' W, at a scale of 1:63,360.

A map was produced which corresponds closely to the lithological interpretation of Consolidated Skeena Ltd. The location of several fold axes remains conjectural due to the strong penetrative regional shearing, the shallow plunge of several folds, and the presence of overburden and lichen. The present work determined the attitude of silver-erythrite-bearing fractures in the Dianne Lake zone.

Property Geology

All rocks exposed are of Precambrian age. The oldest rocks in the area consist of a biotite migmatite (Unit 1), a structurally higher felsic gneiss migmatite (Unit 2) and mylonite (Unit 3). The latter was derived through cataclasis during folding of the migmatites. Younger granite (Unit 4) intrudes these rocks. Diabase (Unit 5) dykes several metres in width trend east-west with steep dips to the south. These dykes are locally intruded by late veins bearing quartz and calcite, with local epidote, chlorite and chalcopyrite.

The biotite migmatite consists of a grey, medium- to coarse-grained neosome with local inclusions bearing biotite-hornblende/cordierite-sillimanite-garnet-pyrite. Minor paleosome rocks include amphibolite (Subunit 1a), quartzite (Subunit 1b), feldspathic quartzite (Subunit 1c) and diopsidic rock (Subunit 1d).

The dominant structure in the area consists of northeast-trending F_3 folds, plunging gently to the northeast. These folds are open, with axial planes subvertical and trending northeast. The amplitude: wavelength ratio varies from about 1:2 to 1:10. Sufficient strain has occurred to produce northeast-plunging rods of paleosome material and penetrative S_3 foliation, parallel to F_3 axial planes, in the neosome of biotite migmatite (Fig. 1c).

Description of Mineralization

Silver and copper occur together in two low-grade zones: 1) west of Doug Lake, measuring about 200 m east-west by 30 m north-south, and 2) west of Dianne Lake, measuring about 90 m east-west by 4 m north-south. The silver, which averages about 14 g/t in trench and drill core assays, favours the biotite-garnet gneiss component of biotite migmatite (Unit 1). Copper averages about 0.35 percent in the Dianne zone, and varies from 0.10 percent to 1.34 percent in the Doug zone. Silver is not visible and probably occurs as disseminations along the foliation. Copper occurs in bornite and chalcopyrite, with local chalcocite. Niccolite is found at trench no. 2 of the Dianne Lake zone. Drill and trench results indicate that copper and silver mineralization occur in two modes: 1) conformable with near-horizontal biotite gneiss bands, and 2) in vertical zones trending east-northeast. These zones may

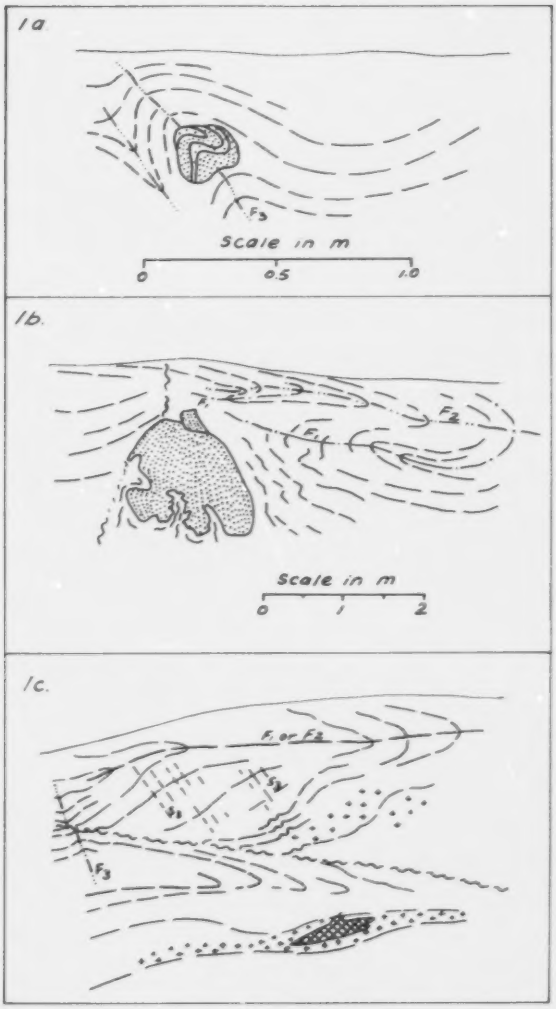

Figure 1—Profiles across biotite migmatite (Unit 1): a, 4+50S, 3+00W, looking northeast; b, 4+80S, 2+80W, looking northeast at east wall of pit no. 2; c, 4+75S, 2+75W, looking southwest. Light stipple, arkose; dense stipple, amphibolite; cross-hatching, cluster of tourmaline crystals; crosses, coarse feldspar. Folds plunge gently to the northeast; F_1 and F_2 are isoclinal, F_3 are open.

have developed along planes of F_3 fracture cleavage.

High-grade silver occurs at the west end of the Dianne Lake zone, with erythrite (cobalt bloom) along near-vertical north-trending

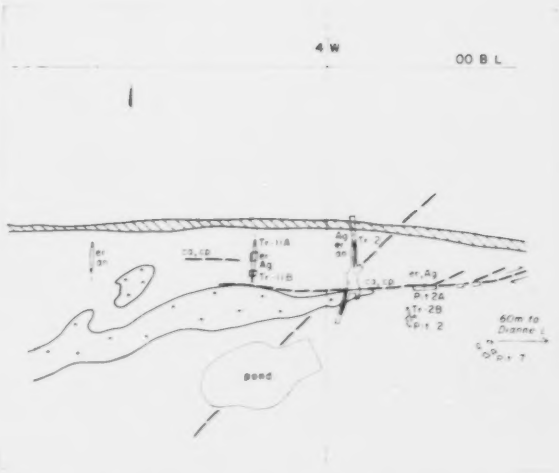

Figure 2—High-grade silver occurrences west of Dianne Lake. North-trending fractures are tensional features and occur near west-trending faults. Ag, silver; er, erythrite; an, annabergite; ca, calcite; cp, chalcopyrite; cross-hatching, diabase; crosses, granite. Not drawn to scale.

fractures. The fractures occur sporadically within biotite migmatite, between a diabase dyke and a granite body (Fig. 2). Assay values exceeding 1700 g/t occur in pit no. 2, and values approaching 30,000 g/t occur in trench no. 2. Annabergite is present locally. The north-trending fractures may have formed during right-hand movement along west-trending faults. Further prospecting to the west seems warranted.

In the northwest quadrant of the area, small amounts of galena and chalcopyrite occur in felsic gneiss (Unit 2) and mylonite (Unit 3). Pyrite is present in trace amounts in biotite migmatite.

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Base Metal Studies: Flin Flon Base Metals Project, Hamell Lake Area

by G. R. Parslow and J. W. Gaskarth

Previous investigations (McDougall et al., 1978, 1979; Parslow and Watters, 1980; Parslow and Gaskarth, 1981) have involved geochemical studies and geological mapping of the Amisk and Annabel Lake areas (Fig. 1). Under the present program the metevolcanic rocks in the area to the east of that previously examined were geochemically sampled, using existing geological maps (Byers et al., 1965) for control. Some 500 samples were collected from locations shown in Fig. 2.

Analytical results from these samples will be compared with those from the rocks in Amisk Lake east (1979), Annabel Lake (1981) and Hanson Lake (Parslow and Gaskarth, this volume) areas. Although most samples were obtained from volcanic lithologies, various intrusives (originally identified by Byers et al., 1965) cutting the Amisk volcanics and younger rocks were also collected to determine if these intrusives are in fact related to the Amisk volcanic episode.

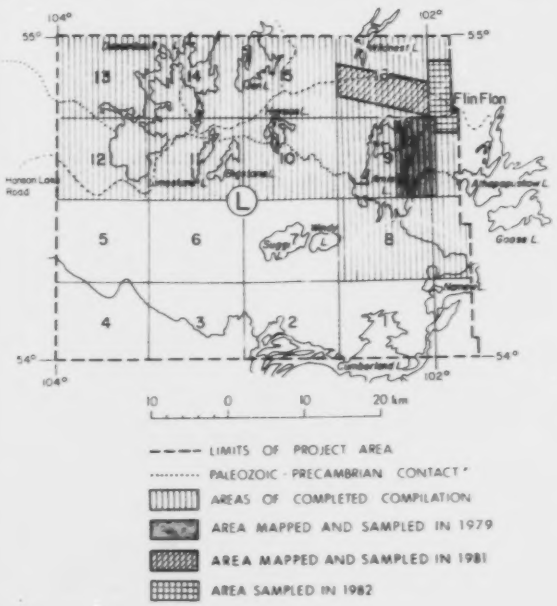

Figure 1 – 1982 sample area.

Although the sampling program did not involve any new mapping, the following few geological observations were made:

1. A major easterly trending shear zone, marked by strongly developed and locally mylonitic planar fabrics and identified in the Annabel Lake area in 1981, passes north of Hamell Lake. It occurs along or close to the contact mapped by Byers et al. (1965) between 'Amisk' volcanics to the north and Missi sediments to the south. Since the rocks north of the shear zone are dissimilar to the type Amisk to the south, further detailed mapping of the zone is required to determine its structural significance. Such a study might help explain the distinctly different metamorphic grades and structural styles between the Kissynew rocks somewhat further to the north and the 'type' Amisk rocks somewhat further south.

2. The volcanic rocks immediately north of the shear zone are dominantly tuffaceous with interbedded fine sediments and minor flow material. Pyritic and pyrrhotitic horizons are common, particularly in the sedimentary units (mapped previously as Amisk sediment). These horizons, which do not have associated alteration zones, are interpreted as barren sulphide layers that developed on top of volcanic rocks on the sea floor. The volcanic rocks south of the shear zone contain much flow material and economic sulphide zones with alteration haloes, suggesting that the shear zone has juxtaposed proximal volcanics (to the south) and distal volcanics (to the north).

3. There is some evidence that the acidic rocks of the Hamell Lake area are both intrusive and extrusive, and representative of a volcanic/subvolcanic suite.

4. Later intrusive rocks in the area are essentially bimodal and to the northeast of Beaverdam Lake a composite sill was encountered. Such activity, along with the numerous dykes in the area, is indicative of at least incipient rifting.

[1] University of Regina.
[2] University of Aston in Birmingham, United Kingdom.
Project contracted out by the Saskatchewan Geological Survey to the University of Regina.

Figure 2 – 1982 sample locations.

Update on Previous Work

The 1979 suite of rocks (800 samples) collected from the Amisk Lake east area, has been analyzed for major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, FeO, MgO, CaO, Na_2O, K_2O, P_2O_5, H_2O^- and LOI) and selected trace elements (Nb, Rb, Sr, Y and Zr), and all sample locations digitized. Although the data have been manipulated (e.g. CIPW and Cation norms, ratios, etc.), interpretation is still at an early stage. A preliminary study of the carbonatized rocks of the area has been completed (Parslow et al., 1981).

To date 200 of the 1100 samples collected in the Annabel Lake area in 1981 have been analyzed. Preliminary examination of the data from both areas suggests that the Annabel Lake samples are more silicic. Comparison of populations of 150 samples from each area show Amisk rocks averaging 51.61 $\pm$ 10.79 percent SiO_2 compared to the Annabel rocks which average 56.67 $\pm$ 7.86 percent SiO_2. This information implies either that the geochemical signature of the volcanics in the two areas is different or that the generally higher metamorphic grade in the Annabel Lake area has affected the chemistry of the rocks. In view of the more fragmental nature of the Annabel Lake rocks, the former hypothesis is preferred.

Acknowledgements

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Mineral Exploration Activity in the La Ronge Mining District and Athabasca Basin

by A. J. Gracie

Uranium exploration drilling activity on the perimeter of the Athabasca Group basin continued at a high level throughout the winter of 1981/82, although many of the properties in the interior of the basin (except those in NTS 74H and 74I) have been allowed to lapse. Only a few companies ran active surface exploration programs during the summer. The level of uranium exploration drilling on targets close to the edge of the Athabasca Group will likely decline again this winter because of the present and projected longer term softness of the uranium market. However, further discoveries will probably be made where Mudjatik and Wollaston Domain pelitic rocks underlie the Athabasca Group.

Key Lake Mining Corp. Ltd. has continued development of the mine-mill complex at Key Lake; the Collins Bay B zone open pit still awaits final government approval; and Canada Wide Mines Ltd. have placed the 'Midwest' Lake operation on hold, pending an improvement in the uranium market.

Gold exploration activity has increased in the La Ronge and Glennie Lake Domains, whereas base metal exploration has remained at a low level and been largely restricted to the Hanson Lake - Limestone Lake area along the southern margin of the Shield. No positive new developments on iron, industrial minerals or other mineral prospects have taken place to diversify mineral production.

Three all-weather highways, to Rabbit Lake, Cluff Lake and Key Lake, give access to northern Saskatchewan. The Department of Northern Saskatchewan expects to have an all-weather highway from Pinehouse to Beauval open to the public by the middle of November 1982.

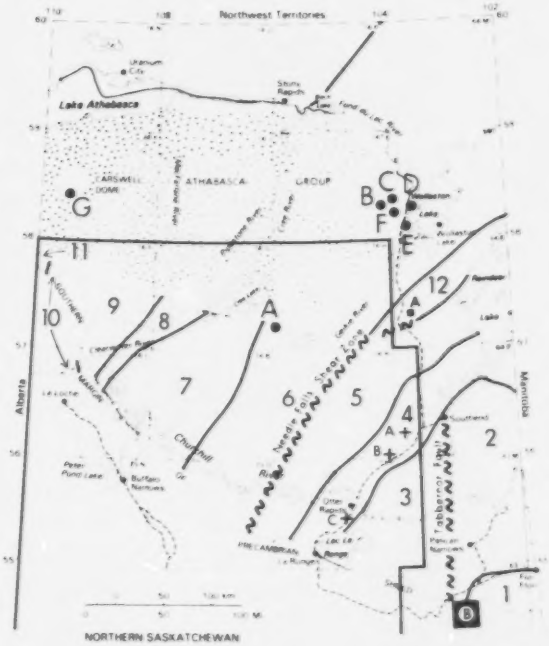

Figure 1—Location of the La Ronge Mining District in relation to geological domains in the Precambrian Shield. Numbered domains: 1. Flin Flon; 2. Kisseynew; 3. Glennie Lake; 4. La Ronge; 5. Rottenstone; 6. Wollaston; 7. Mudjatik; 8. Virgin River; 9. Western Granulite; 10. Clearwater; 11. Firebag; 12. Peter Lake.

Current uranium mines, potential mines and major exploration locations related to the Athabasca Basic (indicated by ●): A. Key Lake Mining Corp., Key Lake; B. Canada Wide Mines Ltd., 'Midwest' Lake; C. Asamera Inc., 11, 11A and 11B zones; D. Gulf Minerals Canada Ltd., Collins Bay and Eagle Point Zones; E. Gulf Minerals Canada Ltd., Rabbit Lake; F. Canadian Occidental Petroleum Ltd., McClean Lake; G. AMOK Ltd., Cluff Lake. Shading represents interior area where the Athabasca Group exceeds 500 m.

Current gold exploration locations (indicated by +): A. Wedge and Weedy Lake occurrences; B. Star Lake property; C. Sulphide Lake property.

Current base metal exploration locations (indicated by ■): A. Peter Lake; B. Hanson Lake—Limestone Lake area.

Uranium

Athabasca Group Perimeter

Exploration drill programs concentrated on detection of conductor- and/or fault-controlled unconformity deposits using the 'Key Lake model' as a basis. The number and average size of the exploration drill programs decreased, with those away from the east and southeast part of the Athabasca Group basin being particularly small. Companies did not seek to drill-define unconformity-related uranium mineralization below about 500 m, the depth limit of the Athabasca Group perimeter area.

New discoveries continued to be made in the area west of Wollaston Lake where uranium deposits are underlain by rocks of the Mudjatik Domain, Wollaston Domain and the Wollaston/Mudjatik Transition Zone. Canadian Occidental Petroleum Ltd. announced discovery of the JEB zone 10 km north of the McClean

Lake deposits. The company has five new mineralized holes from their winter drill program which intersected uranium mineralization at a depth of about 91 m within a zone 122 m long (Northern Miner, May 6, 1982). The assays obtained range from 0.229 percent U over 4.6 m to 8.24 percent U over 7.01 m. Canadian Occidental Petroleum Ltd. has deferred the drill program required to evaluate the size and economic importance of the zone until 1983. P.K. Fountain (Northern Miner, July 15, 1982) reported a rumour that Seru Nucleaire (Canada) Ltd. have made a significant discovery at a depth of more than 400 m by drill-testing of ground-detailed, airborne electromagnetic anomalies.

Eldorado Nuclear Ltd. is negotiating an agreement with Gulf Minerals (Canada) Ltd. in respect to the Rabbit Lake mine-mill and Wollaston properties. As a background to these negotiations, the Rabbit Lake orebody will be exhausted in 1983 and the mill will produce the last concentrate from this ore in 1985. Gulf's proposal to mine the Collins Bay B zone by open pitting has not yet received full provincial government approval. The company had hoped to maintain unbroken production from the Rabbit Lake - Collins Bay area until 1995 by developing the Collins Bay B, D and A zones in succession. Collins Bay B zone reserves (Northern Miner, July 15, 1982) are 12,044 tonnes of U at an average grade of 0.34 percent U; the Collins Bay D zone contains 1935 tonnes U at a grade of 1.623 percent U; and the Collins Bay A zone contains 6654 tonnes of U at a grade of 9.684 percent U.

Canada Wide Mines Ltd. will not go ahead with the Midwest project because of the softness of the uranium market. Asamera Inc. may conclude a farmout agreement to cover the 27 percent of the Dawn Lake uranium project which the company owns (Northern Miner, Aug. 26, 1982). A preliminary estimate of uranium reserves in the four Dawn Lake zones indicates a total of 8056 tonnes of U in 850,000 tonnes of mineralized rock with an average grade of 0.933 percent U (SMDC, 1981 Annual Report).

Athabasca Group Interior

Interest in the Athabasca Group interior has declined and many of the mineral properties in NTS areas 74K, J and G have lapsed. The remaining exploration programs have been oriented toward detection of the source of boulders present in glacial and fluvioglacial deposits, and drilling has been undertaken to test targets in the sandstone pile and/or provide stratigraphic information. Only a few holes were put down to evaluate deep basement, linear geophysical targets.

Crystalline Basement

Companies have shown little interest in uranium exploration outside of the Athabasca Group basin, although mineralization is known to occur at some considerable depth below the underlying unconformity, as for example in the Eagle Point deposit on the west side of Collins Bay. Only two programs tested the uranium potential of basal Aphebian conductors outside of the basin.

Gold

In fiscal 1981/82 the Saskatchewan Mining Development Corporation elected to devote a greater percentage of its exploration budget to the search for gold and base metals.

Grass roots exploration for gold predominated in the La Ronge Domain, with five different companies working on properties which include five new mineral prospecting permits. A clear exploration model has not emerged for this domain, where mineralized quartz veins form the most common prospect.

Several new drill programs have been undertaken on old properties. Energy Reserves Canada Ltd. carried out a 47-hole program on the Waddy Lake property of Waddy Lake Resources Inc; however, due to financial problems they have allowed their option to lapse. In a preliminary report (Waddy Lake Resources Inc. News Release, March 5, 1982) J. Kermeen, a Saskatoon consultant, indicated that 57 drillholes (including 20 new holes by Energy Reserves Canada Ltd.) on the Komis gold zone suggest the potential for 907,185 tonnes of ore grading 4.8 gm Au/tonne. The Saskatchewan Mining Development Corporation drilled on and close to the old Star Lake quartz vein early last winter. Golden Rule Resources Ltd. continued to work on the Wedge and Weedy prospects north of Waddy Lake. DDH 4 drilled in 1981 on the Wedge Lake prospect intersected four zones, which together average 13.71 gm Au/tonne over 26 m (Golden Rule Resources Ltd., 1981 Annual Report). Mahogany Resources Ltd. of Vancouver has purchased an option on the old Decade Development Ltd. Mallard Lake Mine. Because the provincial government has not decided on its land use policy within the Lac La Ronge Provincial Park, no new exploration programs have yet taken place on the Sulphide Lake 'gold belt'.

Gold exploration has also revived in the Glennie Lake Domain with a new prospecting permit at Brownell Lake and drilling early this year by Cominco Ltd. on the Laonil Lake gold property.

Base Metals

The level of mineral exploration for base metals is low. The Saskatchewan Mining Development Corporation carried out preliminary work on their permits east of the Tabbernor Fault and in the La Ronge Domain at the south end of Reindeer Lake. Other SMDC-operated ventures in the La Ronge Domain are concerned primarily with the search for gold. One interesting new project exists in the Peter Lake area of the Peter Lake Domain, where SMDC is investigating the base and precious metal potential of layered gabbroic rocks.

Saskatchewan Precambrian Geological Laboratory, La Ronge

The mineralized core collection housed at the Precambrian Geological Laboratory in La Ronge was expanded with acquisition of cores from Eldorado Nuclear Ltd., Canada Wide Mines Ltd. and Canadian Occidental Petroleum Ltd. The purpose of the collection is to provide a record of northern Saskatchewan's mineral deposits. The non-confidential core within this collection plus an extensive suite of mineralized and host rock samples from various showings and mines are available for inspection at the La Ronge Laboratory.

Mineral Exploration Activity in the Reindeer Mining District

by J. G. Pearson

During 1982, exploration activity in the Reindeer Mining District concentrated on the search for volcanogenic massive sulphide deposits in the Flin Flon, Kisseynew, Glennie Lake and La Ronge Domains, exhalative and lode-type gold deposits in the Flin Flon, La Ronge and Glennie Lake Domains and uranium deposits in the Rottenstone and Wollaston Domains. Exploration activity in the La Ronge, Rottenstone and Wollaston Domains is summarized by Gracie (this volume).

In the district 2302.8 km^2 were staked, of which 63.1 km^2 were in the Flin Flon Domain, 148.9 km^2 in the Glennie Lake Domain, 94.2 km^2 in the Kisseynew Domain, 88.78 km^2 in the Wollaston Domain (all of this in the conversion of permits to claim blocks) and 1069 km^2 in the Phanerozoic cover area. In the Phanerozoic, 547.1 km^2 resulted from conversion by the Saskatchewan Mining Development Corporation (SMDC) of MPP 1077 to claim blocks.

Out of the total acreage staked in the Glennie Lake, Kisseynew and Flin Flon Domains and the Phanerozoic cover area, 690.75 km^2 were staked in the Limestone - Bigstone - Deschambault Lakes area, bounding the Tabbernor Lake Fault. This area contains the Oskikebuk metavolcanics faulted into juxtaposition with Kisseynew gneisses and Hanson Lake metavolcanics. The staking was carried out by Granges Exploration AB, SMDC, Geosearch Consultants and A.L. Parres Ltd.

Two permits were taken out: one of 767.72 km^2 in the Glennie Lake Domain and another of 756.86 km^2 in the La Ronge Domain.

Phanerozoic Area

Granges Exploration AB carried out a large program of line-cutting, horizontal loop EM surveys and diamond-drilling in the Limestone Lake area (Fig. 1). Thirty-three drill holes tested a number of targets in the Limestone Lake area in a program which covered the southerly extension of the Glennie Lake, Kisseynew and Flin Flon Domains.

An important discovery of copper-zinc mineralization between Limestone and Bigstone Lakes was announced by Granges to have resulted from this program (Northern Miner, Oct. 7th, 1982). Four inclined (-60°E) drill holes, 50 m apart encountered

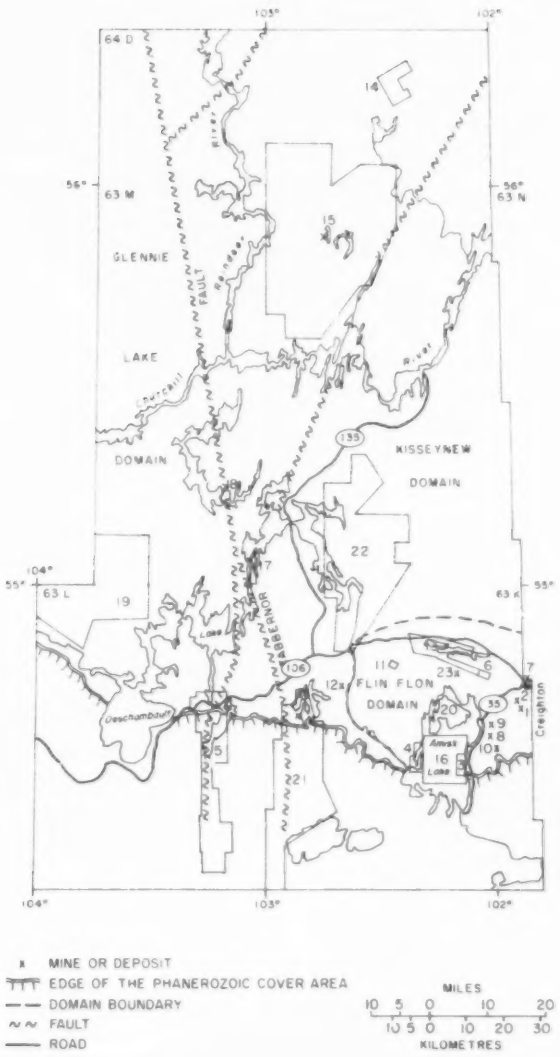

Figure 1—Location of the southern part of the Reindeer Mining District showing present and past producing mines, sub-economic deposits and areas of active exploration. Areas are designated by operator of the project only: Flin Flon Mines Ltd., Rio zone (1), Newcor Mine (2); Granges Exploration AB, East Amisk Lake (3), Muskeg Bay (4), Limestone Lake (5), Wilson Lake (6); Hudson Bay Mining and Smelting Ltd., Flin Flon Mine (7), Birch Lake Mine (8), Flexar Mine (9), Coronation Mine (10), FON zone (11), Sewap Lake (12), Annabel Lake (13), Kyaska Lake (14), MPP 1116 and 1117 (15), Amisk Lake (16); Peter Ballantyne Band, Sandy Narrows Indian Reserve (17), Woody Lake Indian Reserve (18); E.F. Partridge, Brownell Lake (19); SMDC, West Channel (20), Hanson Lake (21), Birch Portage (22); Suneva Resources Ltd., Robinson Creek (23).

significant widths of copper and zinc mineralization in Precambrian volcanic rocks subcropping below a 50 m thickness of Palezoic dolomitic limestones and sandstones. Holes 18, 29 and 31 cut two zones of zinc. The best intersection in hole 29 was 11.33 m of 17.24 percent zinc and 0.17 percent copper. The most northerly hole (30) encountered 34.98 m grading 3.30 percent copper and 0.77 percent zinc, as well as a second thinner zone of copper and two zones of zinc. Minor silver and gold values were also reported. The discovery is open to the north.

In the Pine Bluff area, SMDC drilled two holes to test a large magnetic anomaly. South of Hanson Lake, SMDC carried out programs of horizontal loop EM and magnetometer surveys as well as a three-hole diamond-drill program to test the anomalies.

Flin Flon Domain

In December of 1981, Flin Flon Mines Ltd. completed a 300 m decline and crosscut to further test the gold mineralization in the Rio zone, 4 km south of Creighton. A bulk sample was taken for metallurgical testing. Flin Flon Mines have also acquired the Newcor Mine (Northern Miner, Sept. 23, 1982), a former gold producer located 3 km south of Creighton.

Granges Exploration AB drilled a number of holes in the South Amisk Lake area; two holes were on the east shore and 17 holes tested horizontal loop EM conductors in the Muskeg Bay area. Granges also put down five holes to test EM conductors in the Wilson Lake area.

Hudson Bay Exploration and Development Co. Ltd. (HBED) drilled several targets in the Flin Flon area. One drillhole tested a small copper zone in the Sewap Lake area, two were put down on the FON (Cu-Zn) zone northwest of Amisk Lake and four holes tested the Bomber Lake gold occurrence.

In the Annabel Lake area, HBED carried out horizontal loop EM and magnetometer surveys and a four-hole drill program, and in the Amisk Lake area 640 km of horizontal loop EM and magnetometer surveys were completed together with a five-hole program.

SMDC carried out gold and base metal exploration in the North Amisk Lake area with geological mapping, soil and rock geochemical surveys, horizontal loop and VLF-EM surveys. They drilled two holes to test horizontal loop EM conductors and four to examine areas of gold mineralization.

In the Robinson Creek area northeast of Amisk Lake, Suneva Resources Ltd. continued to evaluate the Vein, Quartz and Bleiler zones (Pearson, this volume). The program consisted of VLF-EM and magnetometer surveys as well as an eleven-hole diamond-drill program on the three zones.

Kisseynew Domain

The Department of Indian Affairs and Northern Development (DIAND) carried out a grass roots exploration program for the Peter Ballantyne Indian Band to evaluate the Sandy Narrows and Woody Lake Indian Reserves. The program consisted of geological mapping, soil and basal till geochemical surveys and a radiometric survey.

HBED undertook horizontal loop EM surveys and geological mapping in the Kyaska Lake area and on MPP 1116 and 1117.

A program of regional and detailed geological mapping, prospecting, horizontal loop EM surveys and lake and soil geochemical surveys on MPP 1114 in the Birch Portage - Belcher Lake area was completed by SMDC.

Glennie Lake Domain

On MPP 1132 in the Brownell Lake area, E.F. Partridge carried out reconnaissance and detailed prospecting surveys as well as detailed VLF-EM, magnetometer and geological mapping surveys in the search for gold mineralization.

Mineral Exploration Activity in the Athabasca District

by D.J. Thomas

Mineral exploration activity in the Athabasca Mining District during 1982 showed a marked decrease compared to 1981. Exploration focused on uranium in the Fond du Lac and Black Lake areas, and gold in the Pine Channel area. Uranium exploration continued to be directed towards unconformity-type mineralization inside and along the edge of the Athabasca Group basin rather than to that of Beaverlodge-type in crystalline basement rocks outside of the basin.

Twenty-five mineral dispositions, totalling approximately 1442 km^2, were registered in the Athabasca region during the year (Fig. 1), compared to 2585 km^2 in the previous year. The Saskatchewan Mining Development Corporation (SMDC) converted MPP 1075 situated in the Fond du Lac River area into 11 claim blocks (546 km^2). This property lies on the northeastern rim of the Athabasca Basin where the relative thinness of the Athabasca succession makes attractive exploration for unconformity-type uranium mineralization. SMDC registered MPP 1126 (777 km^2) in the Wiley Lake area (NTS 740, P), a region of potential gold and base metal mineralization.

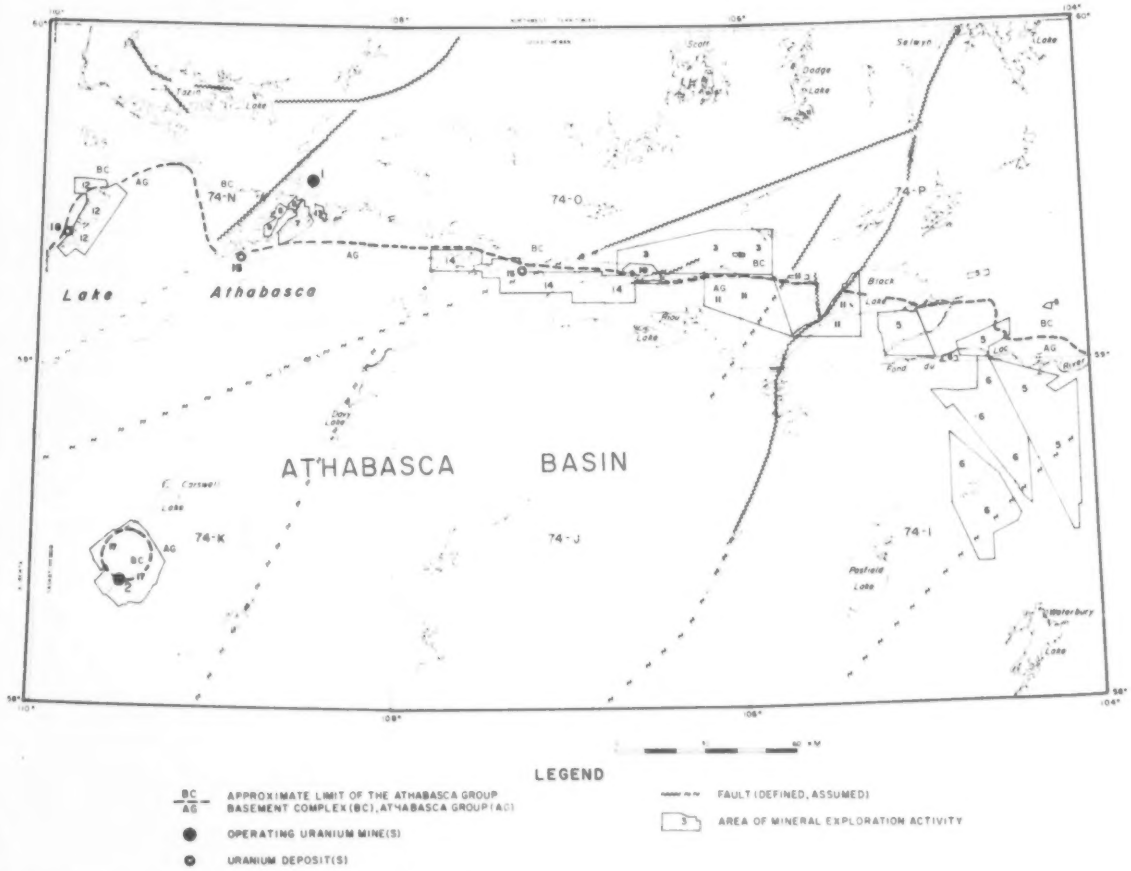

Figure 1—Location of the Athabasca Mining District showing principal mines, proven deposits and areas of active mineral exploration. Areas are designated by operator of property only: Eldorado Nuclear Ltd., Ace-Fay Mine, ceased operations June 30, 1982 (1); Cluff Lake Mining Ltd., Cluff Lake Mine (2); Saskatchewan Mining Development Corporation, Wiley Lake Project (3), Axis Lake Project (4), Black Lake Project (5), Hawkrock Project (6), Lodge Bay Project (7), Crackingstone Project (8), Thompson Island Project (9), Pine Channel Project (10); Eldorado Nuclear Ltd., Stoney Rapids (11), Maurice Bay—Lobstick Island (12), Fishook Bay (13), Fond du Lac II (14), Fond du Lac I (15), Stewart Island (16); AMOK Ltd., Carswell—Cluff Lakes (17); Uranerz Exploration and Mining Ltd., Maurice Bay (18).

A total of 140 mineral dispositions comprising approximately 6262 km^2 lapsed during the last twelve months (Table 1), compared to 13,344 km^2 in the previous year. Most lapsed dispositions were in the Athabasca Group basin.

Table 1 - Area staked and lapsed in the Athabasca District since November, 1981.

NTS Area	Staked (acres)	Lapsed (acres)
74I	605 km^2 (149,453)	572 km^2 (141,425)
74J	NIL	3109 km^2 (768,102)
74K	NIL	758 km^2 (187,271)
74N	NIL	759 km^2 (187,458)
74O	781 km^2 (193,000)	982 km^2 (242,547)
74P	56 km^2 (13,740)	83 km^2 (20,460)
Total	1422 km^2 (356,193)	6262 km^2 (1,547,263)

Uranium production in the Athabasca Mining District was from the Beaverlodge operation of Eldorado Nuclear Ltd. (closed June 30, 1982) and the Cluff Lake operation of AMOK Ltd. Eldorado Nuclear Ltd. announced in December 1981 their intention to cease uranium mining and milling on June 30, 1982. Development of the Ace-Fay deposit began in 1949 and first production came in 1953. The decision to close was determined by depressed uranium prices, falling grades and increasing production costs. Mining operations at Cluff Lake resulted in completion of mining of the very high grade 'D' zone and development of an experimental open pit on the Claude orebody.

Exploration Activity

SMDC operated nine projects in the district during 1982, six in joint ventures with other companies. These projects are as follows:

a) North Saskatchewan Reconnaissance Program. This program covered open ground within NTS areas 74N, O and P and consisted of reconnaissance evaluation of known base and precious metal showings. Field work comprised inspection of selected occurrences to verify and augment existing geological information.

b) Wiley Lake Project. The project area (MPP 1126) extends from the Robillard River in the west to Clut Lakes in the east (NTS 74O, P). Activities during August included reconnaissance mapping, prospecting and lake sediment and lithogeochemical sampling. The area is underlain by northeast-trending gneisses of probable sedimentary origin and basic to ultrabasic rocks of igneous origin (Colborne, 1962). Base metal mineralization is reported to be associated with shear zones in noritic rocks.

c) Axis Lake Project. CBS 2722 is situated at the southeast end of Axis Lake (NTS 74O-5 and 74P-8). Work was performed on the property during August and included retrenching of existing trenches followed by detailed mapping and sampling and general mapping of the disposition. The claim block is reported to be underlain by a large norite body which intrudes metasedimentary gneisses (Colborne 1960, 1962). Massive to disseminated pyrrhotite, pyrite, and minor chalcopyrite mineralization over a width of 5 to 6 m in a siliceous phase of the norite has been traced continuously for 900 m south of the narrows in the south arm of Axis Lake (Beck, 1959).

d) Pine Channel Project. Work was carried out on CBS 6421 and 7107, north of Pine Channel, in joint venture with Golden Rule Resources Ltd., to evaluate fissure vein-type gold mineralization in basement gneisses. Ground geophysics (EM), mapping and lithogeochemical sampling were conducted during the summer. This activity was in follow up to exploration performed on the property by Golden Rule Resources Ltd. in 1981 (Thomas, 1981).

e) Lodge Bay Project. This joint venture project with Denison Mines Ltd. includes CBS 5677 and 5664, an area underlain by Tazin Group quartzites and amphibolites intruded by locally auriferous granites. The exploration program consisted of general and detailed mapping of occurrences as well as lake sediment and lithogeochemical sampling.

f) Crackingstone Project. The project, a joint venture with Urangesellschaft

Canada Ltd., involved work on one claim block and four mineral claims on the Crackingstone Peninsula (NTS 74N); this included a winter geophysical program (IP, resistivity, magnetometer and VLF), followed by bedrock and soil geochemical surveys during the summer.

g) Thompson Island Project. The property comprises five mineral claims held by a joint venture group whose partners are Kintla Exploration Ltd., Rupertsland Resources (U.S.) Inc. and SMDC. Gold mineralization at Thompson Island occurs in quartz-pyrite-arsenopyrite veins which occur either concordant to easterly striking biotite-quartz-feldspar gneisses or within north trending shears (Thomas, 1981). Exploration activity on the property during the summer included general mapping, lithogeochemical sampling and overburden drilling .

h) Black Lake Project. The project area of 33 claim blocks is located in NTS 74I-16 and 74P-1, -2 and -3, and is jointly held by Eldorado Nuclear Ltd., Power Reactor and Nuclear Development Co. (PNC) and SMDC. Line-cutting and ground geophysics (magnetometer, Elfast Turam and gravity) were conducted in January and February of 1982, while summer exploration included Quaternary mapping, prospecting, detailed bedrock mapping (1:20,000 and 1:5,000 scales) and lake sediment sampling. An airborne gradiometer survey was flown over the property during late summer.

d) Hawkrock Project. Union Oil Ltd., Hudson's Bay Oil and Gas Co. Ltd. and SMDC are partners in this venture which includes MPP 1087 and 1088 and CBS 4811, 5899 and 5909 located on the northeastern side of the Athabasca Basin. During the year an Elfast Turam survey and a basal till sampling program were undertaken.

Eldorado Nuclear Ltd. operated five uranium projects in the Athabasca region during 1982, as follows:

a) Fishook Bay Project. This project, located in the Fishook Bay area (NTS 74N-8), covers 51 mineral leases and is held solely by Eldorado Nuclear Ltd. Activity on the property included detailed geological mapping, lithogeochemical sampling, a ground magnetometer survey and a Winkie drill program.

b) Stony Rapids Project. This joint venture with SMDC comprises 16 claim blocks and 1 mineral lease and is located east of Stony Rapids. Exploration work included line-cutting, prospecting, Quaternary and bedrock mapping, Max-Min and magnetometer surveys, and diamond and overburden drilling programs.

c) Fond du Lac I Project. Eldorado Nuclear Ltd. and AMOK Ltd. are joint venture partners on ML 4000, 5251 and 5233 and CBS 5414, located on the northern rim of the Athabasca Basin. Uranium mineralization occurs in Athabasca Group sandstones on the property and has been described by Homeniuk et al. (1980). No further work was carried out in 1982.

d) Fond du Lac II Project. The project area comprises 14 claim blocks. Joint venture partners are SMDC and AMOK Ltd. Exploration activity included detailed prospecting, overburden and diamond drilling, Quaternary mapping, geochemical sampling and an airborne magnetometer survey.

e) Maurice Bay - Lobstick Island. Eldorado Nuclear Ltd., SMDC and PNC hold this area of 10 claim blocks located along the northwest rim of the Athabasca Basin (74N-5). Ground geophysics and a diamond-drilling program were conducted on the property between January and April, 1982.

AMOK Ltd. continued exploration on their mineral dispositions in the Cluff-Carswell Lakes area with major activity around the Peter River and ELF zones over which diamond-drilling programs were conducted.

Activity of the Uranium City Office

A sampling program was initiated at the Uranium City office to establish a record of mineral occurrences, deposits and other important geological features from the Athabasca Mining District. Suites of samples were obtained from mineral occurrences (Table 2) to illustrate mineralization, alteration and unmineralized host rock.

Approximately 1400 m of selected drill core was collected from properties in the Athabasca region and shipped to the Precambrian Geological Laboratory in La Ronge.

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Beck, L.S. (1959): Mineral occurrences in the Precambrian of northern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 36, p. 97-100.

Table 2. Summary of sample suites collected from areas in the Athabasca District. Parentheses indicate type of mineralization in suite collected.

1)	Cluff Lake	74K-5
2)	Maurice Bay	74N-5
3)	Gunnar Mine (U)	74N-7
4)	Box Mine (U)	74N-7
5)	Athona Mine (U)	74N-8
6)	Nicholson Mine (Ni, Co, As, Cu, U)	74N-8
7)	Fishook Bay	74N-8
8)	MacIntosh Bay	74N-8
9)	Eldorado Nuclear Ltd.	74N-9, -10
	i) Dubyna Mine (U)	
	ii) Fay Mine (U)	
	iii) Hab Mine (U)	
	iv) 72-Zone (U)	
	v) Bolger Pit (U)	
	vi) Eagle Pits (U)	
	vii) Martin Adit (U)	
10)	National Explorations Ltd. (U)	74N-9
11)	Nesbitt Labine Eagle-Ace Mine (U)	74N-10
12)	Rix Athabasca Smitty Mine (U)	74N-10
13)	Martin Group	74N-7, -10
14)	Dianne Lake (native Ag)	74N-10
15)	Bob Lake (Cu)	74N-11
16)	Slate Island, Thluicho Group	74N-11
17)	Harper-Morris Lakes (Ag, Pb)	74N-12
18)	Nolan Lake	74N-14
19)	Thompson Island (Au)	740-7
20)	Dinty Lake (Ni)	740-12
21)	Hoidas Lake (REE)	740-13
22)	Axis Lake (Ni)	74P-5

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SEDIMENTARY GEOLOGY INVESTIGATIONS

Further Investigations on Uranium Biogeochemistry in Northern Saskatchewan

by Colin E. Dunn

Investigations conducted in recent years on the uptake of uranium by plants in northern Saskatchewan have produced surprising results. Reports were published in the Saskatchewan Geological Survey "Summary of Investigations" for the years 1979, 1980 and 1981, and the main findings summarized in two papers (Dunn, 1981a, 1982). Twigs of black spruce (Picea mariana) comprise the sample medium which best concentrates uranium in northern Saskatchewan. A practical amount to collect is the latest ten years of growth; hence, unless stated otherwise all data quoted in this report are uranium concentrations, in parts per million, in the ash of the latest ten years of black spruce twig growth. Details of sampling procedures are given by Dunn (1981a).

One outcome of this research is the discovery of a uranium biogeochemical anomaly of great areal extent near Wollaston Lake. The work this year was conducted during a one week period in mid-July. The purposes of the investigation were 1) to define the limits of the Wollaston anomaly and 2) to investigate the biogeochemical response to the 'JEB' zone of uranium mineralization recently discovered by Canadian Occidental Petroleum Ltd.

Regional Study

Background concentrations of uranium in vegetation are commonly about 0.6 ppm (Brooks, 1972). In Saskatchewan, ashed spruce twigs have about 1 ppm U in the Flin Flon and Cypress Hills areas, 2 to 3 ppm U along the road from Southend to the Geikie River, and 2 to 5 ppm U toward the centre of the Athabasca Basin. West of Wollaston Lake many trees have in excess of 100 ppm U. The highest recorded value is 2270 ppm U from near the Rabbit Lake mine. Ten km northwest of Rabbit Lake, and 5 km from any known uranium mineralization, there is up to 1360 ppm U present in dense forest.

The 1981 sampling program defined the southern and western extent of a 10 ppm U contour, which is chosen as an abitrary limit to the Wollaston Anomaly (i.e. 3 to 5 times background for northern Saskatchewan). The 1982 regional study around Wollaston Lake involved the collection of samples from 80 sites, covering an area of about 14,000 km^2; these data supplement those obtained from about 3000 samples analyzed during the previous three years.

The new results show that the Wollaston Uranium Biogeochemical Anomaly, as defined by the 10 ppm U contour, encompasses an area of 10,000 km^2 (Fig. 1). It extends from Unknown and Durrant Lakes in the west, through Hatchet Lake to the north, to the east side of Wollaston Lake, and to approximately the southern end of Wollaston Lake. The southern limit is not precisely defined because several of the most southerly locations sampled yielded assays of about 30 ppm U.

Within the Wollaston Anomaly, two areas of especially high uranium concentrations are outlined (Fig. 1); the 50 ppm contour encompasses an area of about 3000 km^2, and the 100 ppm contour defines an area of 1000 km^2. This is the largest and most intense uranium biogeochemical anomaly on record.

Factors governing the uptake and concentration of uranium in the plants growing on the Athabasca Sandstone and possible mechanisms to explain the anomaly are discussed by Dunn (1982). In summary, the essential conditions are a) substantial uranium deposits; b) permeable bedrock, preferably with steeply dipping fractures; c) upward movement of waters; d) a deficiency of adsorbents in the bedrock; e) a high water table, or deep-rooted plants; f) soils with a low cation exchange capacity; and g) appropriate Eh and pH conditions in the waters, soils, and plants. It is important to note, however, that conditions a, b, c and e are unnecessary if labile (i.e. easily leached) uranium is present in the bedrock, and therefore readily accessible to the plants. Anomalous concentrations of uranium are present in plants that are growing on Aphebian metasediments to the east of the Athabasca Sandstone. Tests conducted this summer confirm that the bedrock has a strong influence on the uranium content of the plants. At one location at the south end of Wollaston Lake, a sample collected from a tree growing in podzol yielded 86 ppm U; 20 m away a tree rooted in biotite gneiss yielded 198 ppm U; and a further 40 m distant a tree rooted in granite gneiss and pegmatite contained 253 ppm U. Differences in uranium concentrations are attributed, therefore, to the amount of labile uranium that is accessible to the roots. The question arises

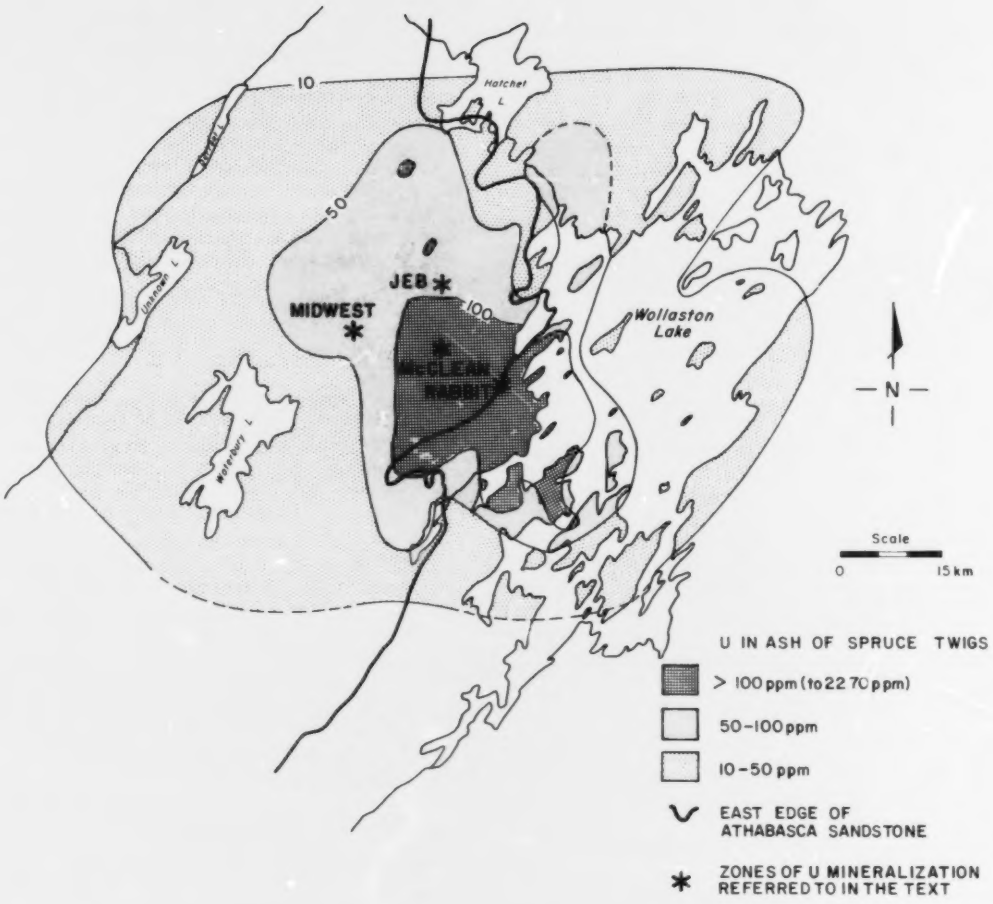

Figure 1 – The Wollaston uranium biogeochemical anomaly: concentrations of uranium in the ashed twigs (latest 10 years growth) of black spruce (*Picea mariana*).

as to why there should be more labile uranium in rocks along the western side than the eastern side of Wollaston Lake. A possibility is that Aphebian rocks in the Wollaston Lake area were covered with rocks of the Athabasca Group prior to the last glaciation, and beneath these sedimentary rocks was a regolith. Uranium in this regolith may have leached downward, entered fractures, and been incorporated in trace amounts in the rocks at crystal boundaries. Thus, the sub-regolith rocks became enriched in uranium, and the present outcrop may constitute the 'root zone' of the regolith which is now releasing its labile uranium to the trees. Tremblay (1982) notes that pitchblende is found "within 100 m below the unconformity as fracture fillings and disseminations in basement rocks". This interpretation explains the presence of relatively high levels of uranium in trees growing on Aphebian terrain close to the Athabasca edge, where less of the 'root zone' has been eroded than farther east, and also explains the eastward decrease in the uranium content of trees on the islands of Wollaston Lake.

Detailed Study

Positive biogeochemical responses to deeply buried uranium mineralization near Wollaston Lake are documented in Dunn (1981a, 1982). The Midwest Zone of mineralization is buried beneath 200 m of Athabasca rocks and shows a weak biogeochemical anomaly. The McClean Zones are beneath about 150 m of Athabasca sandstones and the spruce show a strong response to mineralization, with concentrations up to 500 ppm U. In May of

this year Canadian Occidental Petroleum Ltd. and their partners, Inco Metals Co., announced the discovery of the 'JEB' Zone of uranium mineralization, 10 km north of the McClean Zones (Fig. 1). Mineralization grades up to 9.72 percent U_3O_8 over 7 m at a depth of 90 m, for a tested strike length of 120 m. Five of the ten holes drilled intersected mineralization (Fig. 2).

During a two-day period in mid-July, black spruce twigs were sampled on lines normal to the strike of an EM conductor in order to test the response of the trees to uranium at depth. Samples were collected at 30 m intervals over the conductor, and at 60 m or greater in presumed 'background' areas. (Reconnaissance level studies (Dunn, 1981b) indicate that the background value for spruce twigs should be about 70 ppm U in this area.) Lines sampled were 120 m apart, with closer sampling near the 'JEB' Zone. The environment showed no signs of disruption away from the immediate vicinities of the drillholes; however, limitations were placed on sampling by the presence of muskeg to the southwest of the mineralized zone, and a 10 to 12 year old burnt area to the west and southeast of this zone. Within the 'burn' few spruce trees survived, and labrador tea (Ledum groenlandicum) was collected instead. It was hoped that there would be a constant ratio of uranium in labrador tea stems to uranium in spruce twigs so that both species could be used to produce a biogeochemical map. A survey of the McClean Lake area showed the uranium in spruce twigs to be about twice that of labrador tea (Dunn, 1980). Near the JEB Zone samples of the two species were collected at 14 sites, and on average there was 3.0 times more uranium in the spruce. However, the ratio ranged from 1.2 to 6.4, so the labrador tea data could be used only as a crude guide to uranium enrichments; consequently, the data have not been used in the compilation of the biogeochemical map (Fig. 2). In general, the uranium in the labrador tea followed the same trends as uranium in the spruce.

Spruce twigs with high uranium concentrations occur close to the 'JEB' Zone (Fig. 2), and are flanked by areas with trees depleted in uranium (i.e. below the mean). Contours follow an ENE trend in contrast to the ESE strike of the EM conductor. The highest values (190 ppm U) do not occur directly above the mineralized zone, but are laterally displaced and a few metres to the east. A similar pattern of lateral displacement of the biogeochemical anomalies occurs over the McClean North Zone (Dunn, 1982).

In the southern part of the study area several trees have concentrations of uranium similar to those close to the mineralized zone. The forest fire has left few trees standing, but from the data available it seems that all the remaining trees have relatively high uranium contents. It is noteworthy, however, that these trees have few low branches; hence, samples were collected from a height of 2 to 3 m. Uranium concentrations are higher in the twigs at the tops of spruce trees than twigs at chest height (Dunn, 1980), therefore this factor may have contributed to the increased values.

Discussion and Conclusions

Reconnaissance level studies have defined a 10,000 km^2 area centred on Wollaston Lake within which all black spruce sampled have greater than 10 ppm U in the ash of their twigs. Background levels in northern Saskatchewan are 2 to 5 ppm U. This 'Wollaston Uranium Biogeochemical Anomaly' includes an area of 3000 km^2, in which all samples contain greater than 50 ppm U; this area, in turn, includes a zone covering 1000 km^2 where the twigs have over 100 ppm U, and reach a maximum of 2270 ppm U near Rabbit Lake. Concentrations of up to 1360 ppm U are present in an area of virgin forest, more than 5 km from known uranium mineralization. Soils, peats, waters and near-surface bedrock in the area have normal background levels of uranium. The possibility of airborne contamination of the environment by uranium from the Rabbit Lake Mine has been examined elsewhere (Dunn, 1982) and considered unlikely. In the light of these findings two mechanisms are invoked to explain the anomaly:

1) above the sediments of the Athabasca Group the anomaly is probably a result of the upward migration of uranium ions preferentially along steeply inclined fractures;

2) above metasediments of Aphebian age the anomaly may result from the plant roots absorbing labile uranium from the bedrock. This uranium was derived by downward leaching from a regolith which existed beneath Athabasca sediments but was subsequently removed during the Pleistocene. Slight increases of mobile uranium in fractures and joints in the bedrock would be sufficient to account for the high uranium content of the twigs, because the latter so strongly concentrate the element.

The 'JEB' Zone of uranium mineralization occurs beneath 90 m of Athabasca sandstones. Detailed sampling of trees in this vicinity reveals a positive biogeochemical response. Highest uranium values in the spruce twigs

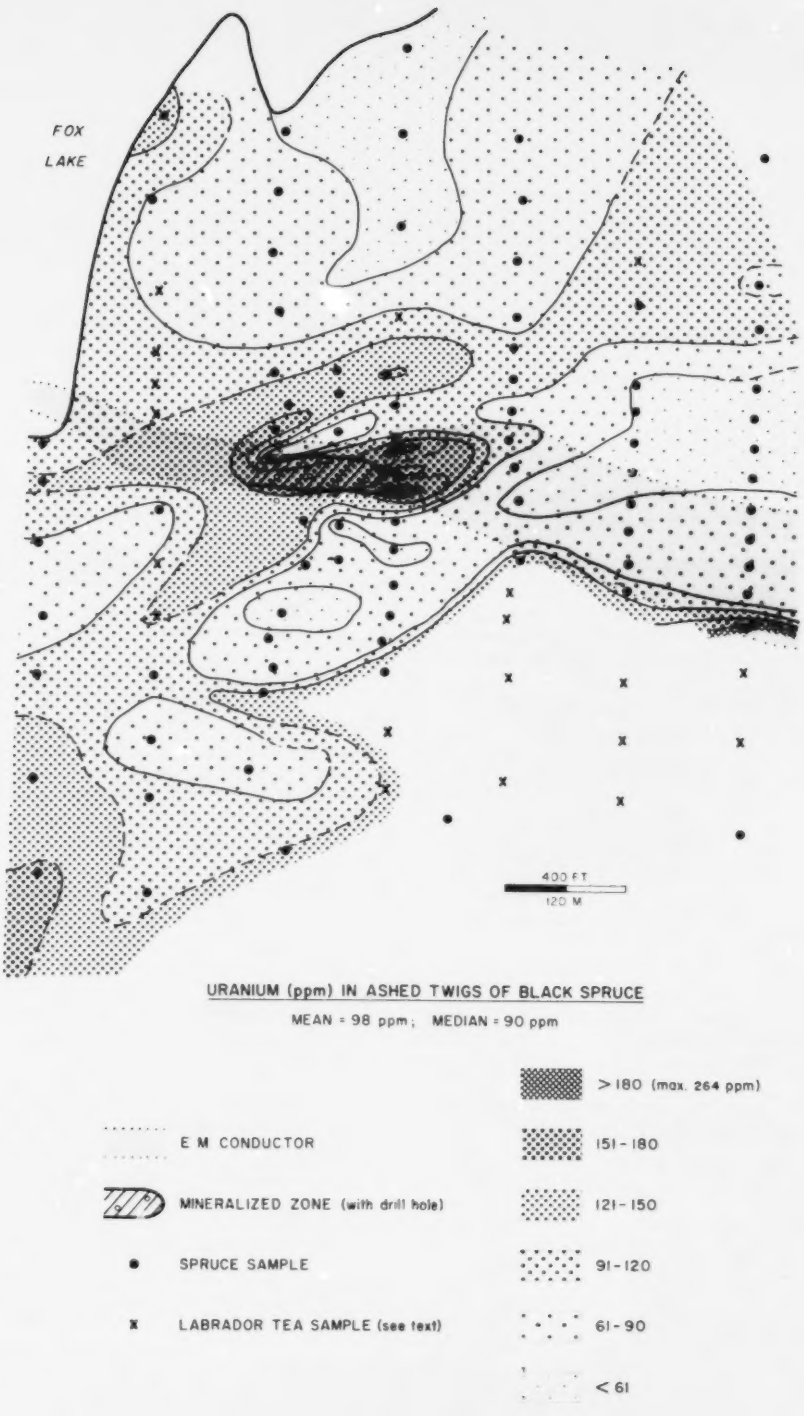

Figure 2—Concentrations of uranium in the ashed twigs (latest 10 years growth) of black spruce (*Picea mariana*) in the vicinity of the JEB zone of uranium mineralization.

occur slightly displaced from the mineralized zone, in a manner similar to that recorded previously from above the McClean North Zone of mineralization.

Acknowledgements

I thank Canadian Occidental Petroleum Ltd. and Inco Metals Co. for their co-operation and hospitality whilst working on their property, and in particular Namik Saracoglu and Roger Wallis. I also thank Dave MacDougall for his valuable assistance in the field.

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The Dawson Bay Formation in Southern Saskatchewan

by Colin E. Dunn

Two studies of the Middle Devonian Dawson Bay Formation were published during 1982. The first is a Saskatchewan Energy and Mines report (Dunn, 1982a), which comprises a detailed study in the Saskatoon area. It places emphasis on the relationship of the formation to the underlying Prairie Evaporite, because a knowledge of the Dawson Bay is of importance to the safety of potash mine operations. The second study is a paper of a more regional nature (Dunn, 1982b), which emphasises stratigraphy, sedimentary environment, diagenesis and hydrocarbon potential of the Dawson Bay Formation. The abstract of this paper follows:

"The Dawson Bay Formation is generally 30 to 40 m thick. It thins in western Saskatchewan and thickens to about 52 m in Manitoba. Over part of eastern Saskatchewan an increased thickness is attributed to the local development of a halite bed at the top of the formation.

Three (locally four) members are defined from type wells in the Saskatoon area. They are, in ascending order, the Second Red Bed, Burr and Neely Members, which are capped locally by the Hubbard Evaporite.

Dolomitic mudstone of the Second Red Bed Member is overlain disconformably by carbonates of the Burr Member. These carbonates are dominated by limestone with a normal marine biota of crinoids, corals and brachiopods, and they are characterized by discontinuity surfaces or "hardgrounds". The Neely Member lies disconformably upon a hardground, and consists of an argillaceous limestone (which grades southward into a non-argillaceous sucrosic dolomite) overlain by sucrosic and microcrystalline bituminous limestones containing reefoid accumulations of stromatoporoids, corals and stringocephalid brachiopods. Overlying carbonates are dolomitized algal mats and stromatolites, which are succeeded by intermixed cryptocrystalline dolomite and felted anhydrite.

These sediments were deposited in shallow shelf seas, and the hardgrounds bear witness to several periods when sedimentation ceased. Quiet conditions during deposition of the Neely Member sediments permitted the development of reefoid mounds up to 5 m thick. Sabkha- like conditions prevailed during the final stages of Neely deposition.

Post-depositional events include partial dolomitization, notably in the lower few metres of the Burr Member, the lower 5 m of the Neely Member (in southern Saskatchewan), and the uppermost part of the Neely Member. Bituminous material entered the reefoid part of the Neely Member prior to extensive plugging of porosity by halite. Later events include local subsidence and fracturing of Dawson Bay sediments in areas where dissolution of the Prairie Evaporite has taken place.

Recent discoveries of hydrocarbons in the Dawson Bay Formation in North Dakota renew optimism for making similar discoveries in the northern part of the Williston Basin. Since depositional conditions and diagenesis were similar throughout the basin, the porous zones of the Neely Member in Saskatchewan may yet yield oil from structural traps."

Present studies include a regional synthesis of data on the Dawson Bay Formation throughout southern Saskatchewan and a detailed examination of the formation in the Esterhazy potash mining district of eastern Saskatchewan. In Saskatchewan the formation is at its thickest near Esterhazy where it is about 52 m, but locally it is in excess of 60 m where halite of the Hubbard Halite is present (e.g. Canberra Langenburg 16 4 21 31 (W1)). In the latter region the Second Red Bed Member is nearly twice the thickness of that in the Saskatoon area, but its sequence of lithologies is the same. Similarly, the Burr Member thickens eastward and comprises a dolomitic zone, overlain by alternating bands of microcrystalline bioturbated limestone, and cryptocrystalline limestone containing borings filled with powdery white carbonate and halite. Hardgrounds, which characterize the Burr Member in the Saskatoon area, are less well developed near Esterhazy, except in the uppermost 3 m of the member. The argillaceous limestone which represents the basal bed of the Neely Member is partially dolomitized near Esterhazy and southward to the North Dakota border, and has a mottled appearance (grey and tan). In southern Saskatchewan this zone's dolomite content increases westward, such that near Coronach, in place of the argillaceous

limestone, there is a 5 m thick bed of featureless sucrosic dolomite plugged with halite (Sohio Standard Gap 16 10 3 25 (W2)).

Throughout most of Saskatchewan there is very little change in facies of the remainder of the Neely Member. It is a microcrystalline to sucrosic limestone, commonly bituminous, with an abundance of large stromatoporoids, corals and stringocephalid brachiopods. This facies is succeeded by dolomite, and then anhydrite at the top of the Dawson Bay Formation.

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Stratigraphy and Oil-Shale Potential of the White-Speckled Shales (Upper Cretaceous), Saskatchewan

by D. F. Paterson

The oil-shales of Saskatchewan are Upper Cretaceous formations, the First White-Speckled Shale (above) and the Second White-Speckled Shale (below). They are present, for the most part, south of Township 50, with northerly extensions in the east and west. McInnes (1913) first reported their occurrence as outcrops in the Pasquia Hills and had them assayed for oil. Beck (1974) mapped the Pasquia Hills area and presented a summary of the economic studies to that date. He estimated that an area of approximately 500 km^2 was amenable to strip-mining and contained some 400 million m^3 of oil. Macauley (1981), by assuming lower grade values, reduced this figure to 200 million m^3.

Present technology is moving away from strip-mining, with all its attendant potential for environmental damage, towards in-situ retorting. This entails creating rubbled oil-shale by drilling and controlled blasting. The shale is then ignited at one extremity and the fire-front advances as air is pumped behind it. The shale ahead of the front is retorted, yielding gases and petroleum liquids which are recovered, and the spent shale is left in place. Thus there is minimal environmental damage from production or waste disposal and the method has no theoretical areal or depth constraints.

The implication for Saskatchewan is that the total area of oil-shale occurrence, and not just the outcrop, may one day have economic production potential. As this area amounts to some 270,000 km^2 in the subsurface, it implies some 108,000 million m^3 of oil, assuming similar thickness to the Pasquia Hills outcrop and Macauley's (1981) lower grade values.

Table 1 shows the nomenclature used in several outcrop studies and its relationship to the generally accepted subsurface terminology as used in Saskatchewan. The latter is being retained here, with the addition of Morden Shale (McNeil and Caldwell, 1981) for the unnamed shale between the First and Second White-Speckled Shales.

Figure 1 is a typical log showing the relationships of the relevant formations in eastern Saskatchewan. Preliminary stratigraphic study has shown that the Second White-Speckled Shale maintains a thickness of 10 to 45 m as it is traced west and north. The First White-Speckled Shale is about 30 m thick in the east and as far west as the Third Meridian. It then thickens, apparently by addition of several units to the upper strata, and reaches thicknesses of 150 m in the extreme west. The details of this change have yet to be worked out, but some of the additional units (e.g. the Medicine Hat Sand) are economically important as gas reservoirs.

Table 1 - Nomenclature used in outcrop and subsurface.

Wick (1974)		Macauley (1981)	McNeil and Caldwell (1981)	General subsurface terminology
Whitemud Fm.		Whitemud Fm.	Pierre Shale	Milk River
Pasquia Hills Formation	Boyne Member	Pembina Fm.		
		Boyne Fm.	Niobrara Fm.	First White-Speckled Shale
	Morden Member	Morden Fm.	Morden Shale	Shale
Favel Fm.		Favel Fm.	Favel Fm.	Second White-Speckled Shale
Lower Colorado		Ashville Fm.	Belle Fourche Shale	Lower Colorado

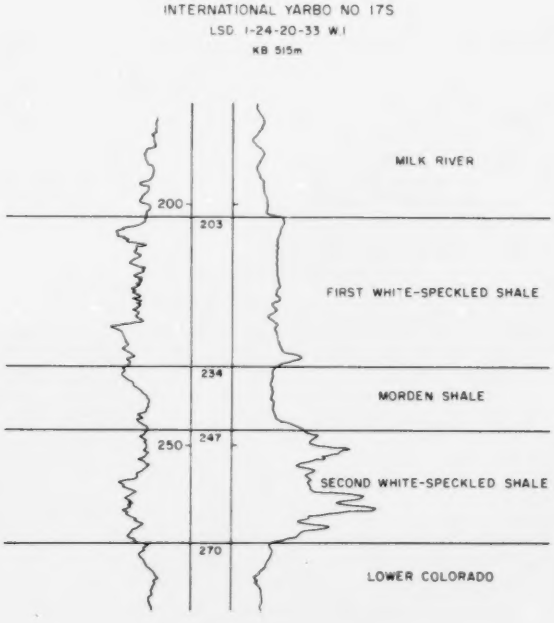

Figure 1 – Typical log showing relationships of relevant formations in eastern Saskatchewan.

To the northwest, the Morden Shale dies out and the two speckled shales merge into a body some 30 to 50 m thick. The exact extent of this area has yet to be delimited, but its boundaries are about 100 km west, south and east of Saskatoon and continue north to the subcrop (Park, 1965; Huffman, 1969).

There are approximately 70 cores available covering at least some part of the strata being studied. Some of these have been examined and sampled by workers at the Institute of Sedimentary and Petroleum Geology in Calgary who intend to do further detailed analyses of oil content. Results are expected in 1983.

When the core analyses are fitted into the stratigraphic framework presently being constructed, a much more precise assessment of Saskatchewan's oil-shale potential will be available. When added to maps of thickness and burial depth, more precise economic potential will also be realised.

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Sedimentation and Depositional Environment of Mannville (Lower Cretaceous) Sediments in the Tangleflags Area, West-Central Saskatchewan

by Malcolm Wilson

Tangleflags Field is located north and east of Lloydminster within the area of Townships 50, 51 and 52 and Ranges 24 and 25 West of the 3rd Meridian.

Within the Mannville Group, the subdivisions followed are those of Fuglem (1970) and Vigrass (1977). It was proposed by Lorsong (1980) that these subdivisions be given formation status and here they will be considered formations for convenience. Figure 1 shows the stratigraphic subdivision of the Mannville. It should be kept in mind that they are lithostratigraphic units and, therefore, undoubtedly diachronous.

The Tangleflags Field yields oil and gas from a number of units within the Mannville, the most consistent of these being the Lloydminster and General Petroleums (GP), but also from the McLaren, Sparky, Waseca, Colony and possibly Cummings.

Subdivision of the Mannville into formations is based almost exclusively on wireline logs. Only in a few enhanced oil recovery pilot projects, such as the Celtic Field (Lorsong, 1979, 1980), is it possible to correlate from core alone, and even in those the correlation is only possible for a portion of the entire Mannville sequence. Basic correlations are made using electric logs (Spontaneous Potential and Resistivity), with further definition being provided by Gamma Ray and Compensated Neutron Porosity - Formation Density logs. Unfortunately, the latter log suite is not available for many of the wells drilled within the Tangleflags area. While it is obvious that core provides the most accurate and reliable data, it must be pointed out that core is taken only in approximately 10 to 15 percent of the wells drilled in the Lloydminster heavy oil area as a whole, Tangleflags being no exception, and that much of this core is discontinuous and in poor condition. All the core within the boundaries of Tangleflags Field and some outside the boundaries has, however, been examined and the data recorded.

Lithostratigraphic Units and Depositional Environment

In the Tangleflags area, all the wells penetrate at least to the Lloydminster Formation and some deeper. Few, however, reach the Paleozoic unconformity, making any detailed picture of the pre-Mannville erosion surface impossible. In addition, it is rarely possible to determine the thickness of the Cummings or to distinguish the presence or absence of the Dina.

The Lloydminster sand is apparently consistent across the entire area. Extensive cross-sections through the Tangleflags area and computer-plotted contour maps of the central part of the Tangleflags Field suggest only gradual changes in thickness. Whether or not this sand is the same sand body across the entire area is not possible to determine from the log signatures and available core data; however, the lateral continuity of the sand is strongly suggested by the generally even thickness and similarity of log character within the area. In addition, the Lloydminster sand is consistently oil saturated indicating, at the very least, hydrodynamic continuity. A number of the density logs show the presence of coal or carbonaceous shale at the top of the Lloydminster, again pointing to lateral continuity.

Where core data are available, they suggest a shoaling (coarsening upwards) sequence with the sands dominated by facies L (lithologic terminology after Lorsong, 1979, 1980), a low angle, cross-laminated sand indicative of upper shoreface or swash-zone sands. The presence of coals and carbonaceous shales above the sands reinforces the interpretation as a shoaling sequence. Underlying the sands are interlayered silts and shales of Lorsong's facies B (generally bioturbated) and shales forming the base of the formation. The general picture provided by the logs and core data is, therefore, one of a shallow marine (coastal) environment with the deposition of an extensive sand sheet as the shoreline progrades. At present, it is not possible to ascertain the direction of this progradation.

Where the core extends across the Lloydminster/Rex boundary, there is clearly a cemented sand present near the base of the Rex Formation. While this sand is not extensively burrowed, it does contain a characteristic type of ichnofossil (Plate 1 gen. et sp. indet.) which, in light of McLane's (1982) work, would appear to indicate the lower to middle shoreface. This concept suggests a

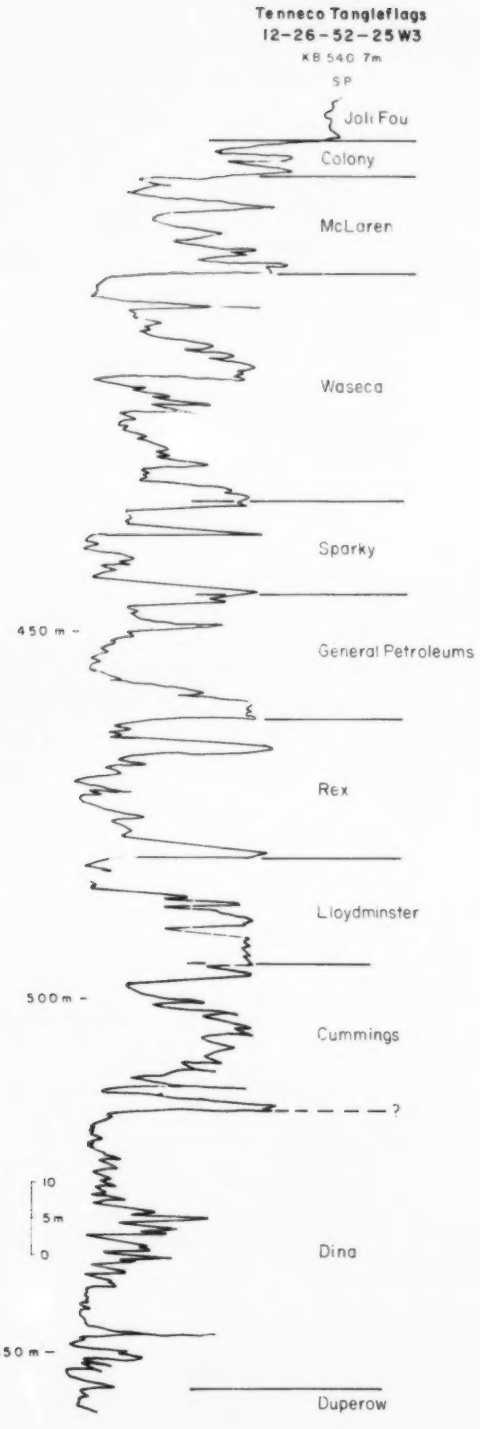

Figure 1—Log 12-26-52-25W3, illustrating stratigraphic subdivision of the Mannville.

post-Lloydminster trangression and a laterally continuous lower Rex sand body. It also lends credence to the above suggestion of an extensive Lloydminster sand sheet.

Plate 1—Characteristic trace fossil from cemented sand, lower Rex Formation.

In the Tangleflags area the Rex is almost entirely water filled and therefore of little economic interest to the oil industry. For this reason there is virtually no core taken except at the base and any interpretation must, of necessity, be made from the available log suites. There is, however, a consistent break (log signature for a shale) at the top of the Rex. This break appears to form a good lithologic marker throughout the Tangleflags area. The logs also suggest that in this area the Rex Formation is a series of stacked sand sheets.

Following the Rex are the GP and Sparky Formations, often difficult to differentiate on the log suites. The available information suggests a shallow marine (shoreface/nearshore) environment becoming terrestrial at the top. Typically, a coal or carbonaceous shale exists at the top of the Sparky. Vigrass' (1977) definition of the top of the Sparky Formation is problematic when there are only logs to consider: just where in the superjacent shale is the hiatus and, therefore, the formational boundary? Since a coal commonly exists at the top of the Sparky/base of the Waseca and is clearly visible on the Neutron and Sonic logs in the Tangleflags area, as well as in the Pike's Peak area (MacEachern, 1982), it would appear to be a convenient marker. Where the coal is absent or only electric logs are available,

the location of the boundary must be estimated based on the probable location of the coal.

Above the Sparky lies the Waseca Formation. Unlike Celtic and many other fields in the Lloydminster area, the Waseca is of minor economic importance in the Tangleflags Field, with the result that there is little information available besides the log suites. The log suites do, however, suggest two, or occasionally more, coarsening upwards sequences culminating in a coal or carbonaceous shale at the top of the formation. Again, the coal represents a convenient lithological marker to define the top of the Waseca.

The McLaren Formation, overlying the Waseca, again typified by a coarsening upwards sequence culminating in a coal, appears to be one more pulse similar to the Waseca in sediment character and log signature.

The Colony Formation, the youngest lithostratigraphic unit in the Mannville, is of minor economic significance with little core data available. The Colony, in the Tangleflags area, is generally a relatively thin, fining upwards sequence capping the Mannville. In places the Colony sand becomes considerably thicker and is coincident with a structural high containing gas or gas and oil. The coincidence of thick sand and structural high suggests compaction rather than tectonic or salt-related feature. In fact, much of the subtle structure in a localized area of the Mannville such as Tangleflags Field may well be a result of differential compaction of the sediments.

Marine Versus Non-Marine Origin for the Mannville

Within the Tangleflags area the sediments of the Mannville, at least from the Lloydminster up, have apparently been deposited in a coastal environment. Each unit (not necessarily formation) represents a transgressive/regressive event frequently culminating in terrestrial sedimentation (the coals and carbonaceous shales). There is little evidence, even in logs where thicker sands exist, of any extensive terrestrial (i.e. fluvial or deltaic) channel deposits, although there are insufficient core data to confirm this.

In the North Tangleflags Field a number of wells display a log signature (Fig. 2) in the Lloydminster or Cummings Formations very similar to that found in the Pike's Peak Waseca 'channel' sands, where some core is available. In Husky Tangleflags North A14-15-52-25W3, the oil-saturated sands display imbricated clay clasts (Plate 2), possibly formed as clay fragments were ripped up and deposited in a channel sand. Samples

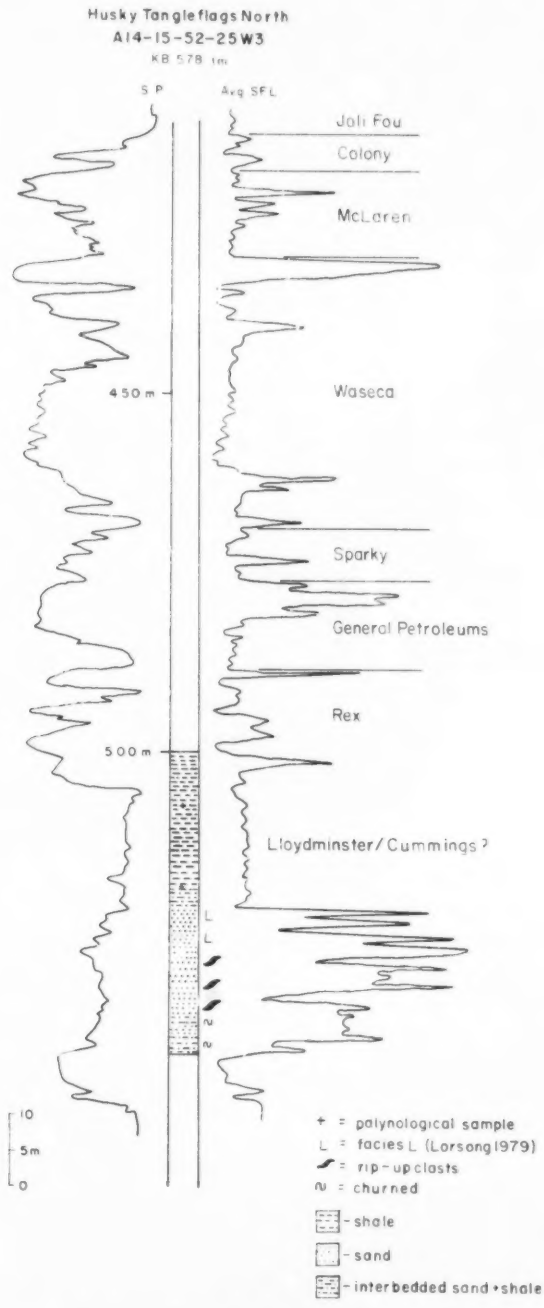

Figure 2—Spontaneous Potential/Resistivity log of Lloydminster/Cummings 'channel' in Husky Tangleflags North A14-15-52-25W3. Note the subdued response of the Spontaneous Potential curve to the sand (shown by core).

from the overlying shale, however, show the presence of dinoflagellates, the higher sample showing increasing marine influence. To further confuse the 'channel' theory, Francana Murphy Tangleflags A6-10-52-25W3 has a similar log signature but the shaley response on the Spontaneous Potential curve is due to shale laminations in the sand rather than clay clasts. A third well, Imperial Tangleflags 13-23-52- 25W3, despite the extremely poor condition of the core, shows no shale at all. Given this conflicting evidence, in Tangleflags at least, there is no concrete evidence for channel sedimentation.

Plate 2—Imbricate shale clasts in oil-saturated sand matrix

In an attempt to gain a better stratigraphic control over the Mannville sediments, Shell Oil Co. has drilled a number of wells with core taken through most of the Mannville. A study of the northerly three wells (A13-1-52-27W3, A13-19-52-23W3 and A7-3-54-25W3) shows non-marine sediments, primarily sands, in the Dina and lower part of the Cummings. In the upper Cummings, marine sediments occur and dominate Mannville sedimentation to the top of the McLaren. Because of their locations away from centres of drilling, it is difficult to correlate these wells with field data; however, in general terms, they do provide strong corroborative evidence for the environmental picture envisioned for the Tangleflags Field.

Conclusions

1. The Mannville is dominated by marine sediments.

2. Lloydminster and younger Mannville sediments represent a series of transgressive/regressive marine pulses, with each pulse terminating in shoreface or coastal terrestrial sediments.

3. The marine sedimentation took place in shallow (shoreface to nearshore to quiet lagoon or embayment) water.

4. The coals and carbonaceous shales, where present, provide convenient lithostratigraphic markers within the Tangleflags area.

Acknowledgements

Thanks are due to a number of my colleagues for their invaluable help during my work on the Tangleflags Field, particularly J. Lorsong and F. Haidl. I would also like to thank J. Christopher, P. Putnam and B. Zaitlin for their informative and useful discussions.

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The Effects of Diagenesis on the Pore Geometry of The Frobisher Beds (Mississippian), Innes Oilfield, Southeastern Saskatchewan[2]

by Maxine C. Akhurst[1]

A pore geometry study of the Frobisher Beds, the reservoir rocks of the Innes Oilfield, was initiated in 1980 in order to determine the optimum location for a secondary recovery program. Production was established from the Innes Field in 1965; since then 70 percent of the estimated reserves available under primary production have been depleted. Preliminary conclusions drawn from the pore geometry study led to the recognition of those lithologies likely to yield maximum return when subjected to secondary recovery techniques. This report demonstrates that diagenesis is the major factor affecting the pore geometry, and thus the reservoir properties of the producing interval of the Innes Field.

The Frobisher Beds are part of the Mississippian Madison Group (Fig. 1). The Innes Field is located within the northwest-southeast trend of Mississippian carbonate oilfields of southeastern Saskatchewan (Fig. 2). Like much of the rest of the Madison Group of the northwest Williston Basin, this formation is composed of massive carbonates.

Within the Innes Field the Frobisher Beds comprise four cycles of sedimentation. Briefly, each cycle consists of a calcareous oolitic-peloidal packstone unit overlain by an argillaceous dolomite or an argillaceous zone (Crabtree, 1979). The impermeable argillaceous intervals separate the reservoir into four discrete pools.

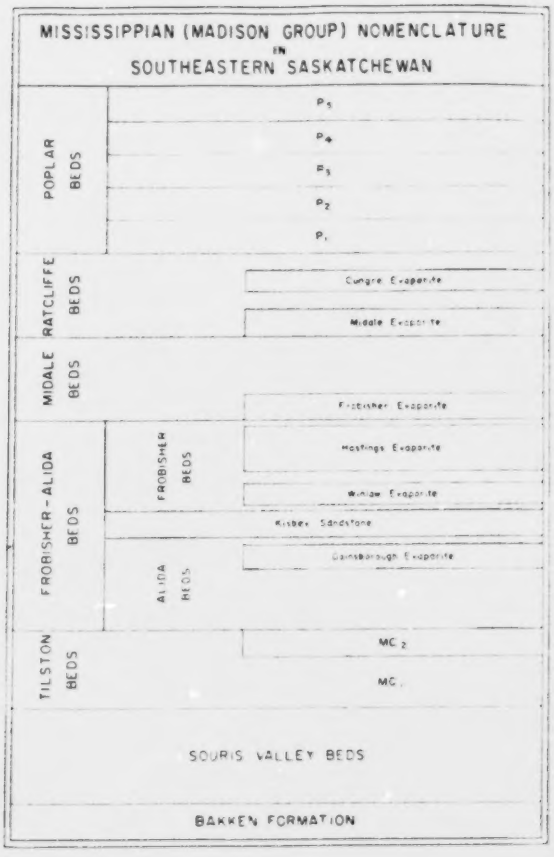

Figure 1—Mississippian (Madison Group) nomenclature in southeastern Saskatchewan (from Fuzesy, 1966).

Mercury Capillary Analysis

The procedures followed here are described by Purcell (1949) and Wardlaw and Taylor (1976) with modifications by Leibel (1980) for the equipment used.

A number of petrophysical parameters may be determined from mercury capillary pressure curves (Fig. 3). Those parameters most relevant to reservoir potential for the lithologies illustrated in this report include maximum mercury saturation, unsaturated pore volume and ejection efficiency. Initial entry (Fig. 3) records that percentage of the pore system that occurs as vuggy porosity greater than 400u in diameter. The presence of such large pores does not enhance the ejection efficiency (Akhurst, 1981). Abundant pore throats of similar size increase the ejection efficiency and thus the reservoir quality, and appear as a deflection of the injection curve to the left.

Mercury capillary injection curve shapes permit the classification of the calcareous Frobisher Beds into reservoir and non-reservoir rocks (Akhurst, 1981). Those

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[2]M.Sc. thesis in preparation, D.M. Kent, Supervisor.

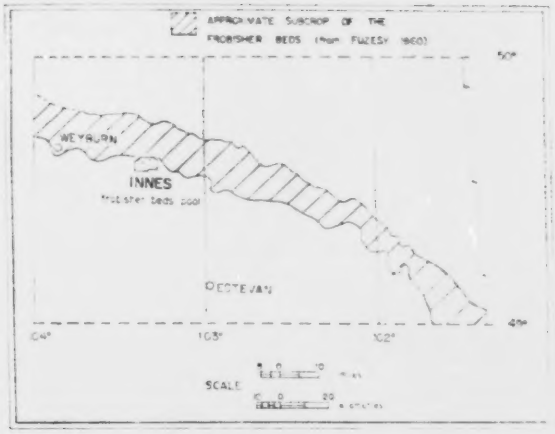

Figure 2—Location map.

lithologies with the greatest reservoir potential are oolitic-peloidal packstones with primary or secondary interparticle porosity.

Diagenetic Sequence

The following is an idealised diagenetic history of the Innes Field based on the examination of approximately thirty thin sections:

1. Pre-lithification matrix dissolution that enhances interparticle porosity.
2. Isopachous calcite fringe cement or coarsening bladed calcite cement.
3. Corrosion of fringe or bladed cements.
4. Non-isopachous equant calcite that contains iron-rich calcite zones.
5. Equant dolomite which may pre-date or post-date the equant calcite.
6. A second phase of corrosion which affects both pore and vug margins.
7. Stylolitisation affects all cements.
8. Anhydritisation.

Not all the features are present in a given lithology nor are all the phases illustrated in this report.

Method of Study

Reservoir-type lithologies yield similarly shaped capillary pressure curves, the variations in curve shapes reflecting different pore geometries. In hand specimen the lithologies appear comparable as their differences can only be discerned at microscopic or sub-microscopic levels. Comparison of the following injection curves and thin section photomicrographs shows that the contrasts in pore geometry are attributable to distinct diagenetic histories.

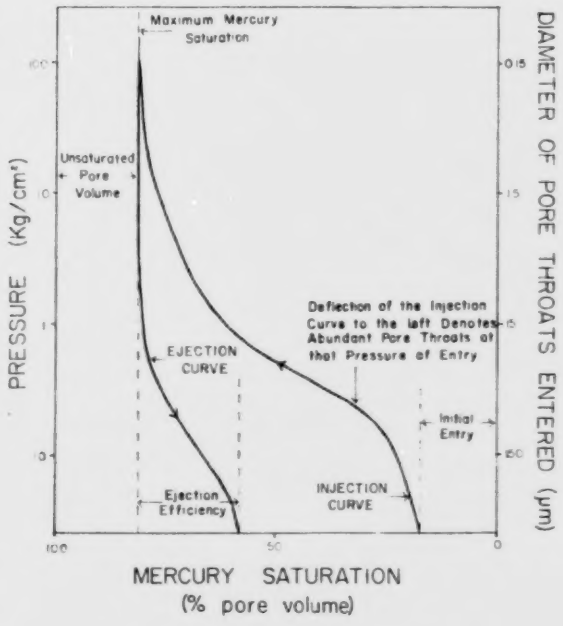
Maximum Mercury Saturation
Unsaturated Pore Volume
Deflection of the Injection Curve to the left Denotes Abundant Pore Throats of that Pressure of Entry
EJECTION CURVE
Initial Entry
Ejection Efficiency
INJECTION CURVE
PRESSURE (Kg/cm²)
DIAMETER OF PORE THROATS ENTERED (µm)
MERCURY SATURATION
(% pore volume)

Figure 3—Petrophysical parameters determined from mercury capillary injection and ejection curves.

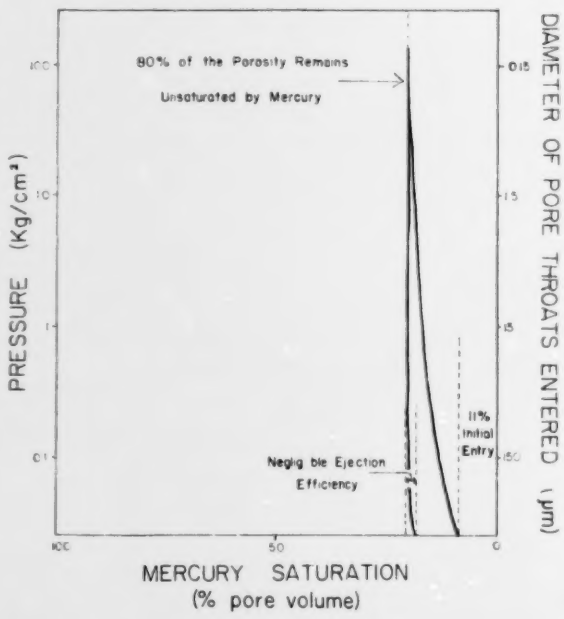

Figure 4—Capillary pressure curve of non-reservoir lithology.

Non-Reservoir Lithology (Fig. 4, Plate 1)

The mercury capillary injection curve shows that after an initial invasion of 11 percent of the pore volume, there was very little mercury penetration. Eighty percent of the pore volume is too small to be entered by mercury and must be considered ineffective. The associated thin section photomicrographs reveal that the initial entry invaded vugs. This example must be considered as a non-reservoir lithology due to diagenetic changes to the pore system. An isopachous fringe cement (Plate 1) lines all the interstices and occludes the smallest voids. Subsequent formation of equant iron-rich calcite crystals leaves only the largest vugs as open porosity. Although late-stage corrosion of open vug margins has occurred, the ejection efficiency is almost negligible, producing a non-reservoir rock.

Poor Reservoir Lithology (Fig. 5, Plate 2)

The initial 25 percent invasion of the porosity enters large open vugs. Subsequent invasion is continuous but slight with a small peak between 15u and 4u pore throat diameters. A coarsening bladed calcite cement has completely closed the finer porosity; the second peak of pore throat invasion probably enters residual intercrystal sheet pores at the centre of the cemented voids. It would appear that the largest pores were not totally occluded, permitting the passage of corroding fluids and the creation of secondary porosity. Both maximum mercury saturation and ejection efficiency are low, producing a poor reservoir rock.

Good Reservoir Lithology (Fig. 6, Plate 3)

The 'interparticle porosity' curve of this cemented packstone indicates an unusually large entry of pores within the 100u to 3u range of pore throat diameters. Intragranular pores appear to be the cause of the abundant fine porosity where selective dolomitization of grain parts has taken place. The ejection efficiency and therefore the reservoir quality of this lithology is good but would have been better if the dolomitic intercrystal porosity had formed a continuous pore system.

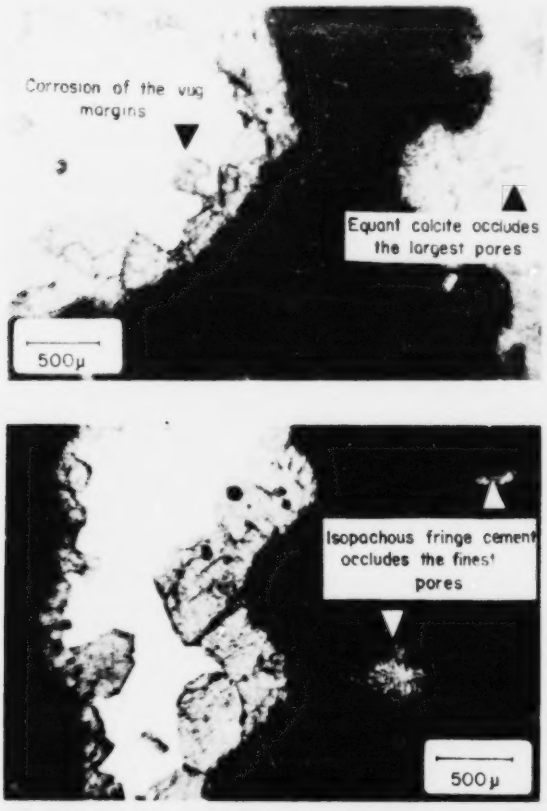
Corrosion of the vug margins
Equant calcite occludes the largest pores
500µ
Isopachous fringe cement occludes the finest pores
500µ

Plate 1 – Photomicrographs of non-reservoir lithology.

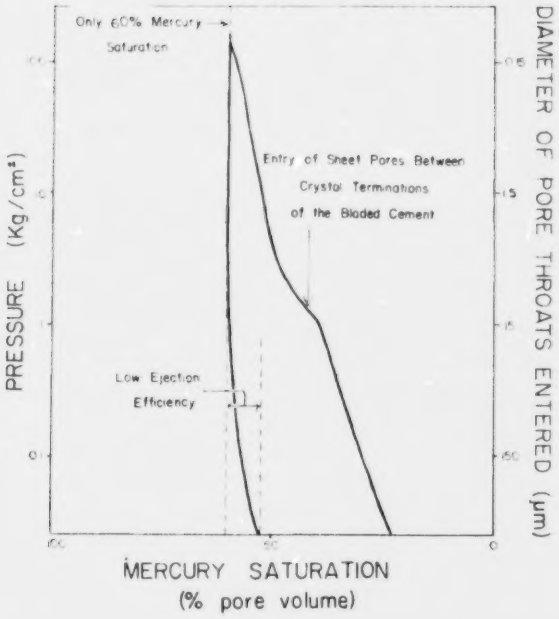
Only 60% Mercury Saturation
Entry of Sheet Pores Between Crystal Terminations of the Bladed Cement
Low Ejection Efficiency
PRESSURE (Kg/cm²)
DIAMETER OF PORE THROATS ENTERED (µm)
MERCURY SATURATION
(% pore volume)

Figure 5 – Capillary pressure curve of poor reservoir lithology.

Plate 2—Photomicrograph of poor reservoir lithology.

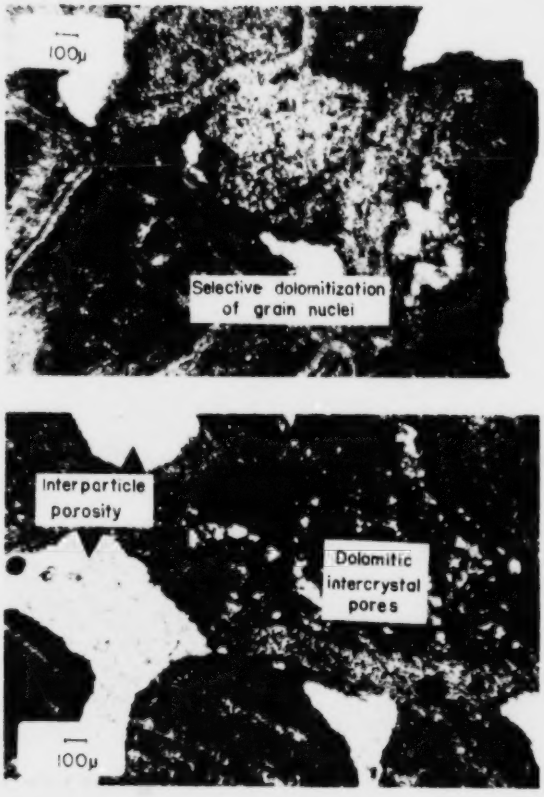

Plate 3—Photomicrographs of good reservoir lithology.

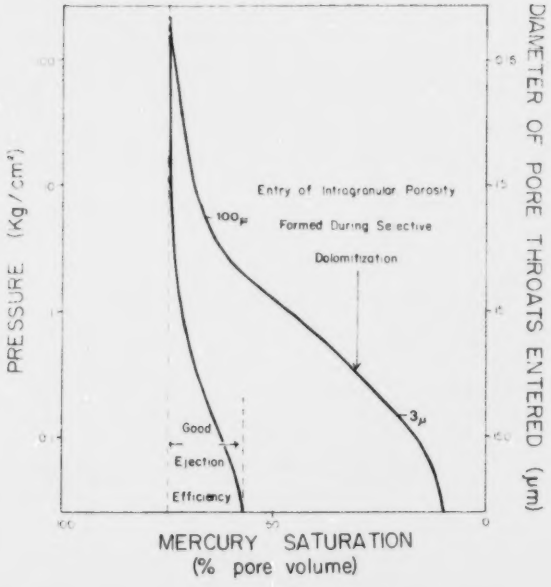

Figure 6—Capillary pressure curve of good reservoir lithology.

Very Good Reservoir Lithology (Fig. 7, Plate 4)

The 90 percent mercury saturation demonstrated by the injection curve in Fig. 7 indicates that only 10 percent of the porosity is likely to remain saturated by water. The greater part of the pore system would therefore be available to the entry of hydrocarbons. Development of this pore geometry with its associated high ejection efficiency is attributable to two phases of cement dissolution. This lithology is a grainstone cemented by fine bladed calcite crystals which occlude the smaller pores. A period of calcite dissolution re-opened the interstices and later cements of equant calcite and equant dolomite crystallized on the original ooid margins. Secondary interparticle porosity, forming a continuous pore network, accounts for the high ejection efficiency seen on the capillary ejection curve. A second phase of calcite corrosion affected the equant calcite and was followed by dolomitization of the crystal margins and vug enhancement.

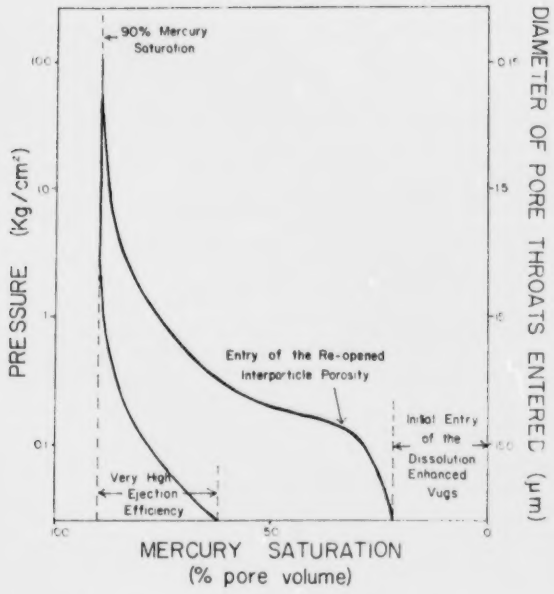
90% Mercury Saturation
Entry of the Re-opened Interparticle Porosity
Initial Entry of the Dissolution Enhanced Vugs
Very High Ejection Efficiency
PRESSURE (Kg/cm²)
DIAMETER OF PORE THROATS ENTERED (µm)
MERCURY SATURATION (% pore volume)

Figure 7—Capillary pressure curve of very good reservoir lithology.

Conclusions

The reservoir interval of the Innes Field is essentially composed of oolitic-peloidal packstones; however, the reservoir quality of a given sample depends on its diagenetic history.

The presence of a fringing isopachous calcite cement or a coarse bladed calcite cement, which occludes fine interparticle pores, results in non-reservoir or poor reservoir qualities. Equant iron-rich calcite crystals occur in almost all of the Innes Field rock types regardless of their reservoir properties. Late stage corrosion of pore and vug margins was common and appears to increase ejection efficiency.

The Innes Field reservoir lithologies generally show some degree of dolomitization. Consideration of examples not illustrated here suggests that dolomitization and distribution of crystals may enhance reservoir quality.

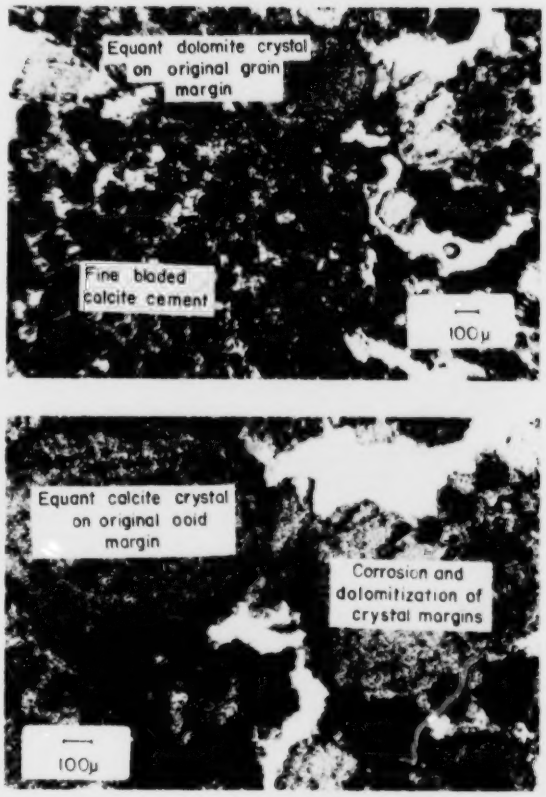
Equant dolomite crystal on original grain margin
Fine bladed calcite cement
100µ
Equant calcite crystal on original ooid margin
Corrosion and dolomitization of crystal margins
100µ

Plate 4—Photomicrographs of very good reservoir lithology.

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Bull. Can. Petrol. Geol., v. 24, p. 225-262.

Calcitized Anhydrite: Its Significance as an Exploration Tool in the Mississippian Tilston Beds of Southeastern Saskatchewan

by John Kaldi and Alf Hartling[1]

The Tilston Beds occur as the lowermost portion of the Mission Canyon Formation of the Mississippian Madison Group in southeastern Saskatchewan (Fig. 1). The Madison Group is composed of cyclic carbonates and evaporites which thicken toward the centre of the basin in west-central North Dakota, reaching a maximum thickness of 700 m.

The general depositional model for the Madison cycles comprises quiet water carbonate sediments on a broad, flat shelf interior which intermittently gave way to higher energy deposits of a relatively narrow shelf margin. Supratidal sabkha deposits prograded from the northeast to blanket much of the shelf-interior and shelf-margin areas while basin-slope and basin sediments accumulated further downdip (Kent, 1980).

Post-Mississippian erosion truncated Madison sediments such that progressively younger beds subcrop basinward. Producing oilfields in southeastern Saskatchewan generally are aligned roughly parallel to these subcrop traces. The area of study for this report is immediately downdip from the Tilston Beds subcrop (Fig. 2).

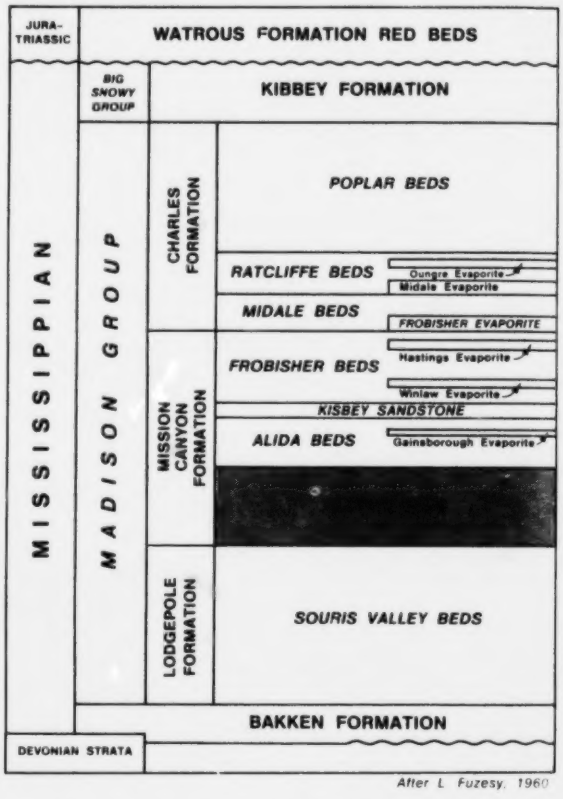

Figure 1 – Mississippian stratigraphic chart for southeast Saskatchewan.

Description of Sediment Types

The uppermost Tilston Beds contain nodular to enterolithic anhydrite which displaces surrounding patterned, pink to red, microcrystalline dolomite (Plate 1). These evaporites resemble ones forming in modern sabkha sediments (Evans et al., 1969; Kinsman, 1969; Shearman, 1978), and a similar supratidal origin is postulated. The supratidal sediments of the Tilston Beds range from 1 to 5 m in thickness throughout the study area.

Locally, anhydrite nodules from the Tilston Beds are calcitized ($CaSO_4$, has been replaced by $CaCO_3$); the distribution of calcitized nodules is presented in Fig. 2. Calcitized nodules are recognized by their opaque white colour which contrasts markedly with the transluscent blue-greys of unaltered anhydrite. The full range of replacement textures, from unaltered to wholly calcitized nodules, is shown in Plate 1 and can be seen in many other cores.

Microscopic examination of calcitized nodules reveals relic rectangular cleavage traces (which correspond to the tabular habit of the precursor anhydrite) in an otherwise nondescript calcite mosaic texture. This is similar to features described by Shearman and Fuller (1969) from the Middle Devonian Winnipegosis Formation of Saskatchewan. Scanning electron photomicrographs show lath-shaped calcite pseudomorphs after anhydrite (Plate 2). Traces of hydrocarbons are present on a few crystal faces.

[1] Saskatchewan Oil and Gas Corporation, Regina.

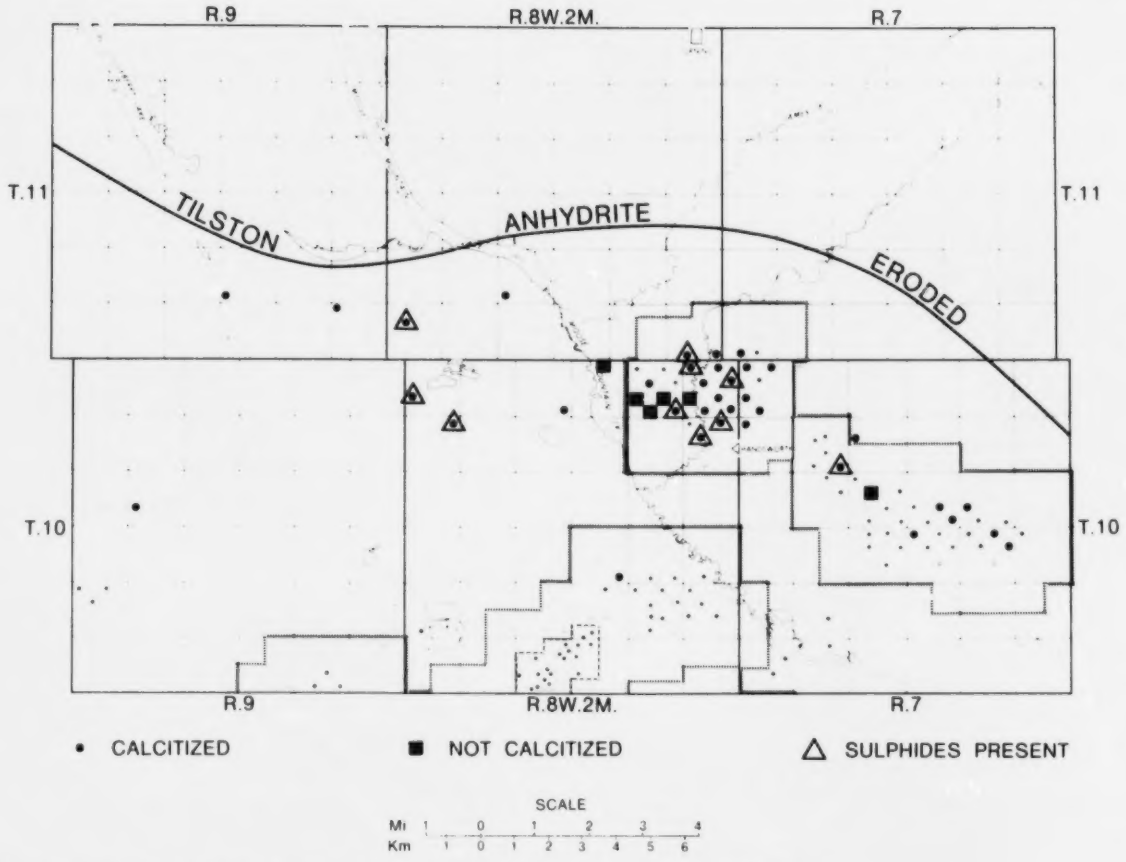

Figure 2—Distribution of calcitized anhydrite and associated sulphide mineralization within the study area.

The patterned dolomite interbedded with the evaporites is similar to features described by Dixon (1976), Kendall (1977) and Elliott (1982). This patterned texture results from the dissolution of ephemeral evaporites at or very near the sabkha surface during rainy seasons. The colour variations result from the weathering of insoluble residues or of disseminated sulphides which formed by the reduction of original sulphates (Kendall, 1977).

Minor amounts of galena, sphalerite and possible marcasite occur in the outer portions of calcitized nodules, but not in the unaltered nodules. Sulphide mineralization is attributed to the local activity of sulphate-reducing bacteria. A similar process is detailed by Harwood (1980) to account for sulphides associated with calcitized anhydrite nodules in Permian carbonates of England.

Several calcitized nodules are surounded by a "rind" of ferroan dolomite which, in some cores,has been oxidized to give it a deep red hue. The presence of ferroan dolomite suggests that a localized reducing environment surrounded at least some of the calcitized nodules.

Model for Calcitization

A three-stage model to account for the calcitization of anhydrite nodules in the Tilston Beds is proposed (Fig. 3).

Stage 1: Deposition of Tilston carbonates took place in the shelf-marginal zone. Shoaling produced carbonate buildups of bioherms and/or ooid sand bodies which created local positive topographic features on the sea-floor. A normal marine faunal assemblage was present.

Stage 2: As the Tilston sea regressed, the carbonate build-ups may have remained as isolated islands in a generally restricted marginal sea

Plate 1—Core slab showing relationship of calcitized nodules (ca) to unaltered anhydrite nodules (anh) and patterned dolomite (pd).

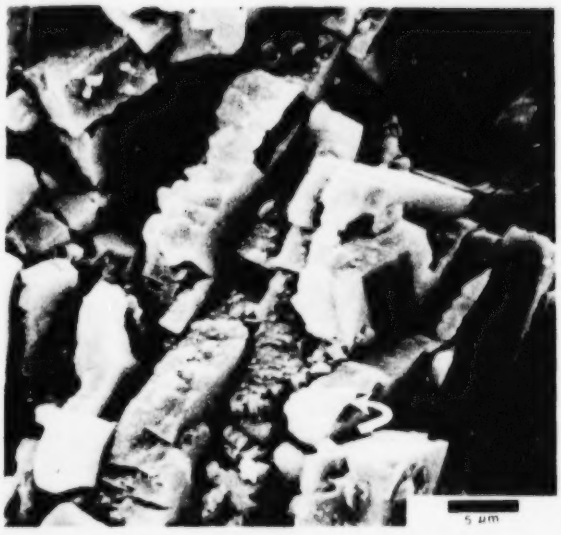

Plate 2 – SEM micrograph of lath-shaped calcite pseudomorphs after anhydrite precursor. Note hydrocarbon residue on crystal faces (arrow).

whose waters were most likely anoxic, allowing the survival of few organisms. Sabkha sediments, consisting of nodular to enterolithic anhydrite interbedded with mottled dolomite, prograded across the shelf interior and filled local topographic depressions.

Stage 3: Meteoric water was introduced onto the sabkha surface during rainy seasons. This water percolated through the carbonate build-ups (which protruded through much of the sbkha sediments) and dissolved $CaCO_3$ to cause minor karsting in the carbonate bodies.

Groundwater enriched with CO_3^{2-} moved down the gentle regional dip and entered laterally equivalent sabkha sediments. These fluids, in the presence of sulphate-reducing bacteria, caused calcitization of anhydrite and sulphide mineralization according to the reaction:

$$CaSO_4 + (Pb,Zn)SO_4 + (H_2 + CO_2) \rightarrow CaCO_3 + (Pb,Zn)S + H_2O + H_2S$$

The zone of calcitization is therefore found down-dip and, to a lesser extent, laterally to the carbonate build-ups. As the CO_3^{2-} in the groundwater is used up, the process decreases in intensity.

Implications of the Model

The most significant aspect of calcitized anhydrite is its potential use in hydrocarbon exploration. For example, Fig. 4 shows a fairly typical Williston Basin stratigraphic trap. A permeability decrease is formed by the pinch out of a more permeable carbonate build-up (bioherm or ooid shoal) against less permeable lime muds. Where the sequence is capped by dense evaporites, its reservoir potential is high. These build-ups are very difficult to map in the subsurface, even using the most sophisticated seismic techniques. The presence of calcitized anhydrite in a well may thus provide the explorationist with an indication of a nearby build-up, and a potential oil pool. Subsequently, the development geologist may use the limits of extent of calcitized nodules to help define pool boundaries during delineation drilling.

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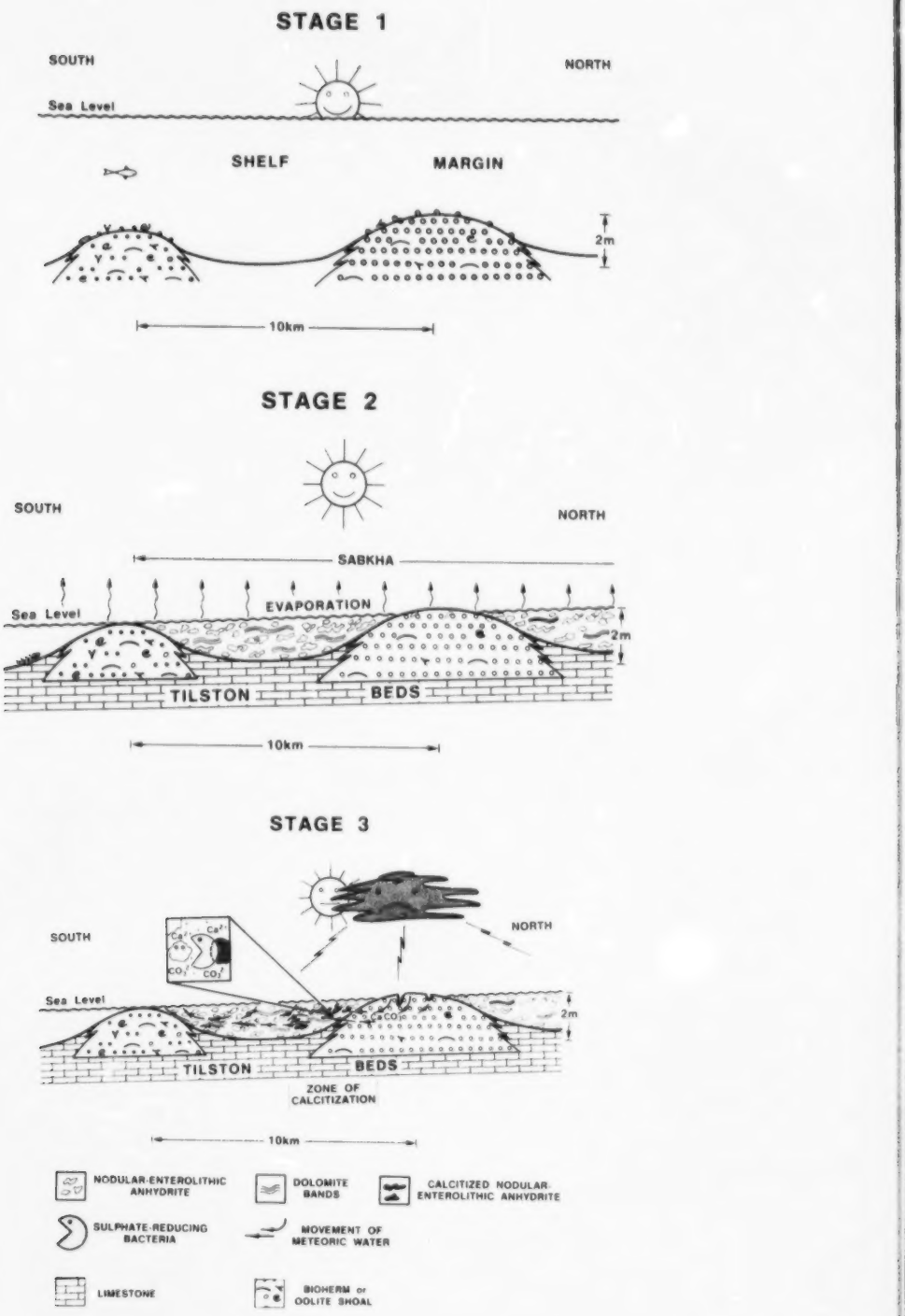

Figure 3 – General calcitization model:
a) Stage 1: Normal marine shelf margin carbonate sedimentation. Bioherms and/or oolite shoals form local relief on sea floor.
b) Stage 2: Progradation of sabkha sediments over marine carbonates.
c) Stage 3: Influx of meteoric water during rainy seasons; recharges through carbonate build-ups penetrating sabkha surface and calcitizes laterally equivalent anhydrite nodules in association with sulphate-reducing bacteria.

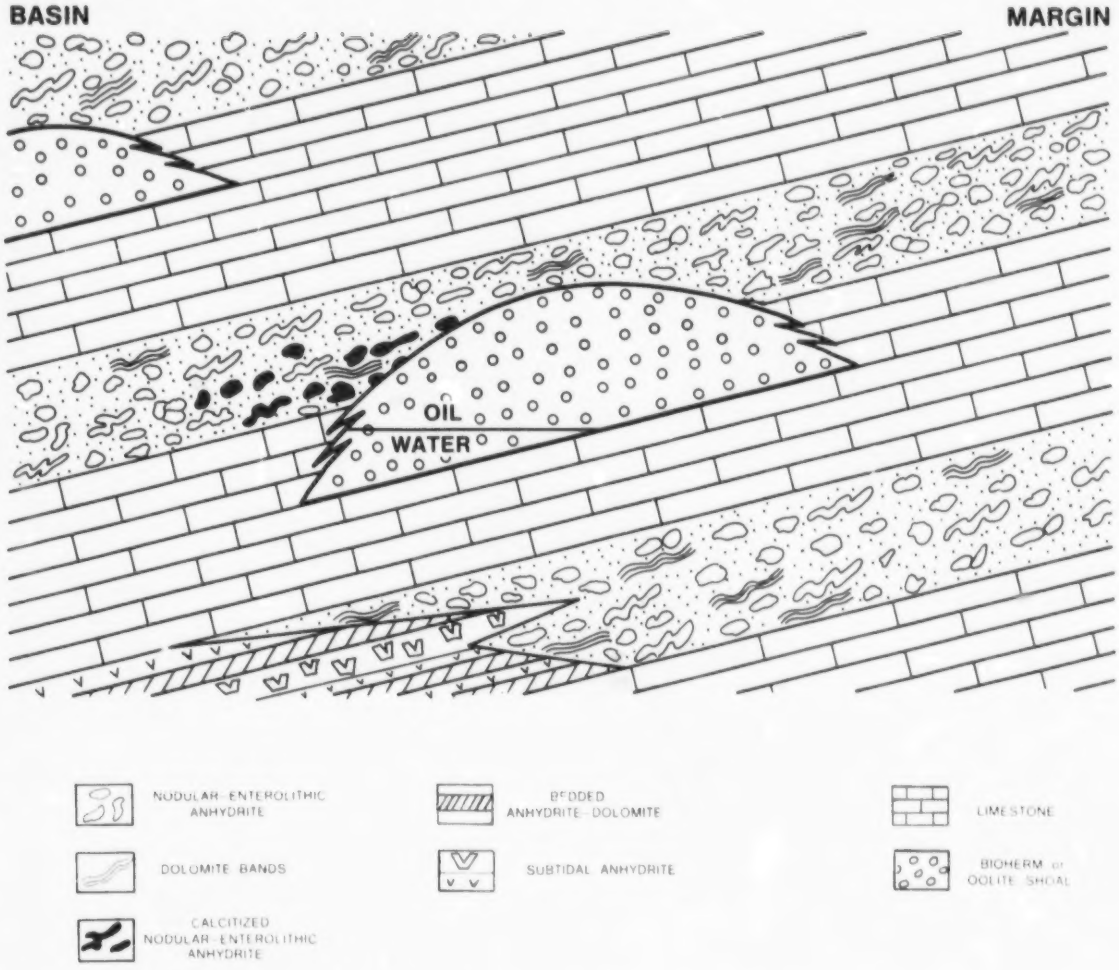

Figure 4 – Typical stratigraphic trap found in the Williston Basin

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Underground Storage Potential of the Bedded Salt Deposits of Saskatchewan: Project Outline and Rationale

by Frank Simpson[1] and Garrett M. Connolly[1]

Solution-mined caverns in bedded halite deposits of the Middle Devonian Prairie Evaporite have been utilized by industrial operators in Saskatchewan for the underground storage of hydrocarbons since 1962. Both dry natural gas (DNG) and liquefied petroleum gases (LPG) are currently stored in these salt caverns. At one location, waste mercury compounds are contained and confined in salt caverns which were washed to supply brine for a chlor-alkali plant. In addition, there is potential for underground storage in caverns, resulting from the solution-mining of halite and potash respectively at two separate sites in the province, and in excavated subsurface space, originating from conventional room-and-pillar mining of potash-bearing strata at ten other locations.

Evaporites are interbedded with carbonates and generally subordinate argillaceous rocks throughout the Ordovician to Mississippian carbonate-evaporite succession of southern Saskatchewan (Christopher et al., 1971), but only the Middle Devonian Prairie Evaporite and the Upper Devonian Davidson Evaporite member of the Souris River Formation incorporate halite deposits with the potential for commercial development of storage caverns over a wide area. Holter (1969) described lithologic variation in the Prairie Evaporite of southern Saskatchewan, and a recent account by Worsley and Fuzesy (1979) presented new data on the formation in the southeastern part of the province. The stratigraphy of the Davidson Evaporite in southern Saskatchewan was discussed by Lane (1964), and a paper by Kendall (1976) dealt with occurrences of the unit to the west and east of Saskatoon.

A major potential hazard to the safe operation of storage facilities in the bedded salt deposits of southern Saskatchewan is presented by naturally formed structures caused by the collapse of superincumbent strata at the sites of localized solution of halite and other soluble minerals. The fracture-bounded sinks commonly associated with these features provide possible conduits for the vertical movement of fluids stored in nearby artificial caverns. Accounts of the distribution and time of formation of multistage salt-solution features associated with the Prairie Evaporite were presented by Kent (1968) and Holter (1969). Simpson and Dennison (1975) discussed the significance of solution-generated collapse features as sources of potential hazard in relation to the subsurface disposal of fluid industrial wastes. Simpson (1978) evaluated the main causes postulated for localized salt solutioning in the light of extra-basin tectonic controls, notably the interaction of plates along the western margin of North America.

During the summer of 1982, a study to evaluate the underground storage potential of the bedded salt deposits of Saskatchewan was initiated with the support of Saskatchewan Energy and Mines as a Master's thesis project by the junior author. An assessment of the possible environmental impact of existing salt caverns was undertaken. Four areas (Melville, Regina, Saskatoon and Unity, Fig. 1) were studied in detail. Structure-contour and isopach data on up to nine correlation surfaces, ranging from Middle Devonian to Late Cretaceous in age, were analyzed to investigate the trends of solution-generated collapse features next to the salt caverns. In addition, a questionnaire was designed and distributed to companies engaged in underground storage operations in Saskatchewan. This questionnaire comprises 38 questions concerning the design and operation of a salt cavern storage facilities and it was used to summarize the experience of industrial operators in a standardized way.

Current Status of Salt-Cavern Storage

Twenty-six salt caverns in eight storage facilities listed in Table 1 are used for hydrocarbon storage in Saskatchewan. Solution-caverns for purposes other than hydrocarbon storage are listed in Table 2. These include solution-mining projects for potash exploitation by Kalium Chemicals Ltd. in Twp 17 Rge 25W2, for halite production by Dexter Chemicals Ltd. in Twp 40, Rge 22W3, and for industrial waste-disposal by the Saskatoon Chemical Division of the Prince Albert Pulp Company Ltd. in Twp 37 Rge 5W3. Mercury compounds derived from the operation of a chlor-alkali plant are disposed of at the last facility (Simpson and Dennison 1975). In addition the locations of experimental solution-mining test wells are shown in Table 2.

1 Department of Geology, University of Windsor, Windsor, Ontario.

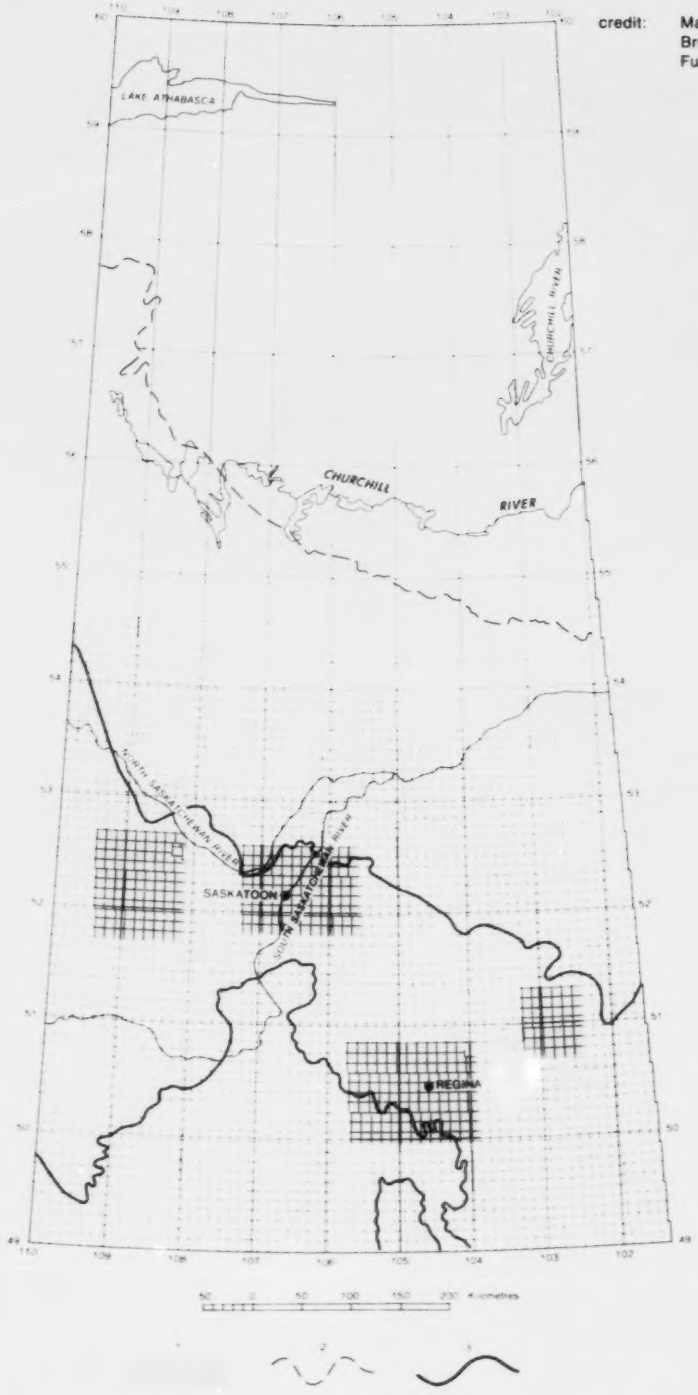

Figure 1 – Sketch map showing location of areas of detailed study in southern Saskatchewan. 1, study area; 2, southern perimeter of Precambrian Shield; 3, edge of Prairie Evaporite (Middle Devonian) salt.

Table 1. Salt-Cavern Storage Facilities in Saskatchewan (After Simpson and Dennison, 1975)

Ref. No.	Salt-Cavern Storage Facility	Product Stored	Number of Caverns	Year First Storage	Average Cavern Depth (m)	Total Storage Capacity (x 10^6 m^3)
1	Dome Melville (sec. 29-22-6W2)	LPG	5	1962	1057.7	0.62
2	SPC Brewer (sec. 15-23-6W2)	natural gas	1	1963	1027.2	10.05
3	Pacific Elenwold (sec. 22-16-18W2)	LPG	2	1966	1542.3	0.16
4	SPC Regina (sec. 27-16-20W2)	natural gas	4	1964	1639.2	96.9
5	Procor Regina (sec. 29-17-20W2)	LPG	8	1972	1687.1	0.69
6	SPC Prud'homme (sec. 12-38-28W2)	natural gas	2	1965	1008.9	33.4
7	SPC Landis (sec. 36-37-18W3)	natural gas	2	1976	1233.2	59.47
8	Dome Kerrobert (sec. 34-33-22W3)	LPG	2	1971	1328.9	0.12

Locations of the salt-cavern storage facilities listed in Table 1 and the main caverns from Table 2, mentioned above, are shown in Figure 2, together with the sites at which conventional room-and-pillar mining of potash in the Prairie Evaporite is carried out.

Towards a Systematic Approach to the Siting of Salt Caverns

One of the major advantages of underground storage of fluids in salt caverns lies in the fact that the injection-related movement of energy and materials (Fig. 3) is restricted to a known volume of solution-mined subsurface space. This movement can be carefully controlled with the aid of a suitable pressure-monitoring device. This is in contrast to injection systems, in which the storage space is provided by naturally occurring or artificially enhanced porosity, where the volume of injection-affected subsurface space is not fixed with precision and is frequently affected by regional and local characteristics of the hydrogeologic regime (Simpson and Dennison, 1975). As noted above, salt-cavern storage facilites in close proximity to naturally occurring solution-generated collapse features present the possibility of hazard, arising from fluid escape. The main stages of decision analysis in a study of legislation against air pollution (Ellis and Keeney 1972) were followed by Simpson and Dennison (1975) in their study of waste injection systems.

These stages are presented as a model for the system-design process in Figure 4. The questionnaire-related part of the present study will facilitate optimization of

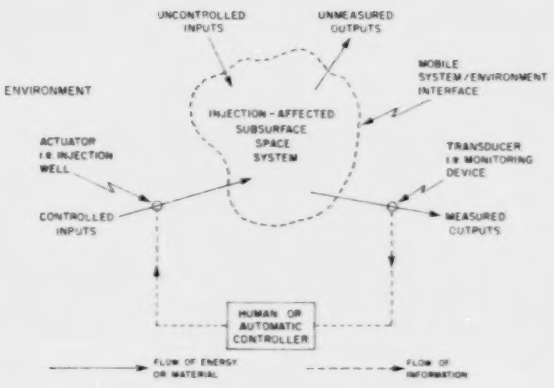

Figure 3—The flow of energy and materials across the interface between the injection-affected subsurface space system and its environment.

Table 2. Controlled Solution Removal of Prairie Evaporite, Exclusive of Storage Cavern Development in Saskatchewan (After Simpson and Dennison, 1975)

	Solution Well(s)	Completion Date/on Stream	Solution Interval (m)	Current Status	Fresh-water Source	Brine-Disposal Formation	Remarks
1.	General Petroleums Kutawagon 6-29 (Ctr. W½ 6-29-30-21W2)	Jan. 1958	1046.1	abandoned	surface	Mannville	solution-mining test well
2.	Lumsden Potash 1 Bethune 2-17-20-23 (SW 2-17-20-23W2)	Dec. 1966	- 1063.8	suspended	Mannville	surface	solution-mining test well
3.	Lumsden Potash 3 Bethune 2-17-20-23 (SE 2-17-20-23W2)	Apr. 1967	-	suspended	Mannville	surface	solution-mining test well
4.	Lumsden Potash 4 Bethune 2-17-20-23 (NE 2-17-20-23W2)	Aug. 1967	1249.7	suspended	surface	surface	solution-mining test well
5.	Lynbar Duval 4-22-25-23 (SW 4-22-25-23W2)	Jan. 1967	1249.7	suspended	surface	surface	solution-process experimental well
6.	SWP Boulder Lake 16-18-30-23 (Ctr. 16-18-30-23W2)	Jul. 1963	1066.8	suspended	surface	Mannville	experimental potash-brine test well
7.	SWP 3 Boulder Lake 16-18-30-23 (Ctr. 16-18-30-23W2)	Aug. 1963	1066.8	suspended	surface	Mannville	solution-mining test well
8.	Stony Beach No. 2 (SW 12-11-17-24W2)	Apr. 1961	1706.9	abandoned	Mannville	Mannville	potash solution-mining test well
10.	Kalium Chem Stony Beach (Secs. 24, 25 & 26 -17-24W2)	May 1961	-	operating	surface	Souris Valley	the only commercial potash solution-mine operation in the world
11.	Findlater Potash 16-10-21-25 (Ctr. 16-10-21-25W2)	Apr. 1962	1524.0	abandoned	Mannville	Birdbear	potash pilot well
12.	Findlater Potash 16A-10-21-25 (Ctr. S½ 16-10-21-25W2)	Sept. 1962	1524.0	abandoned	Mannville	Birdbear	potash pilot well
13.	Northern Rochdale 3-26-37-5W3 (Sec. 3-26-37-5W3)	1967	1024.0 - 1094.2	operating	surface	Mannville	brining well
14.	Northern Rochdale 4-26-37-5 (Ctr. 4-26-37-5W3)	Jul. 1962	1039.4 - 1086.9	operating	surface	Mannville	brining well
15.	Northern Rochdale 5-26-37-5 (Sec. 5-26-37-5W3)	1967	1024.7	operating	surfac	Mannville	brining well
16.	DSP 4-2-37-6 (Ctr. 4-2-37-6W3)	Jun. 1962	975.4	abandoned	surface	Mannville	potash solution-mine test well
17.	DSP 4-2A-37-6 W3 (Ctr. 4-2-37-6W3)	Jun. 1962	975.4	operating	surface	Mannville	potash solution-mine test well
18.	Prairie Salt Company No 3 (Sec. 14-4-40-22W3)	1967 ?	1097.3	operating	surface	Duperow[1]	brining well
19.	Prairie Salt Company No. 4 (Sec. 14-4-40-22W3)	1969	1097.3	operating	surface	Duperow[1]	brining well
20.	Prairie Salt Company No. 1 (NE 15-4-40-22W3)	Feb. 1947	1097.3	suspended	surface	surface	brining well
21.	Prairie Salt Company No. 2 (NE 15-4-40-22W3)	Jun. 1947	1097.3	plugged back to SWD	surface	surface	brining well
22.	Werbata No. 2 (Ctr. 7-24-41-24W3)	Jun. 1946		abandoned	Belly river	surface	poor core recovery due to unsaturated drilling fluid

Note: Solution interval, unless a sonar survey was available, is the approximate landed casing depth.

[1]Prior to 1973 disposal was to a surface lagoon and lake.

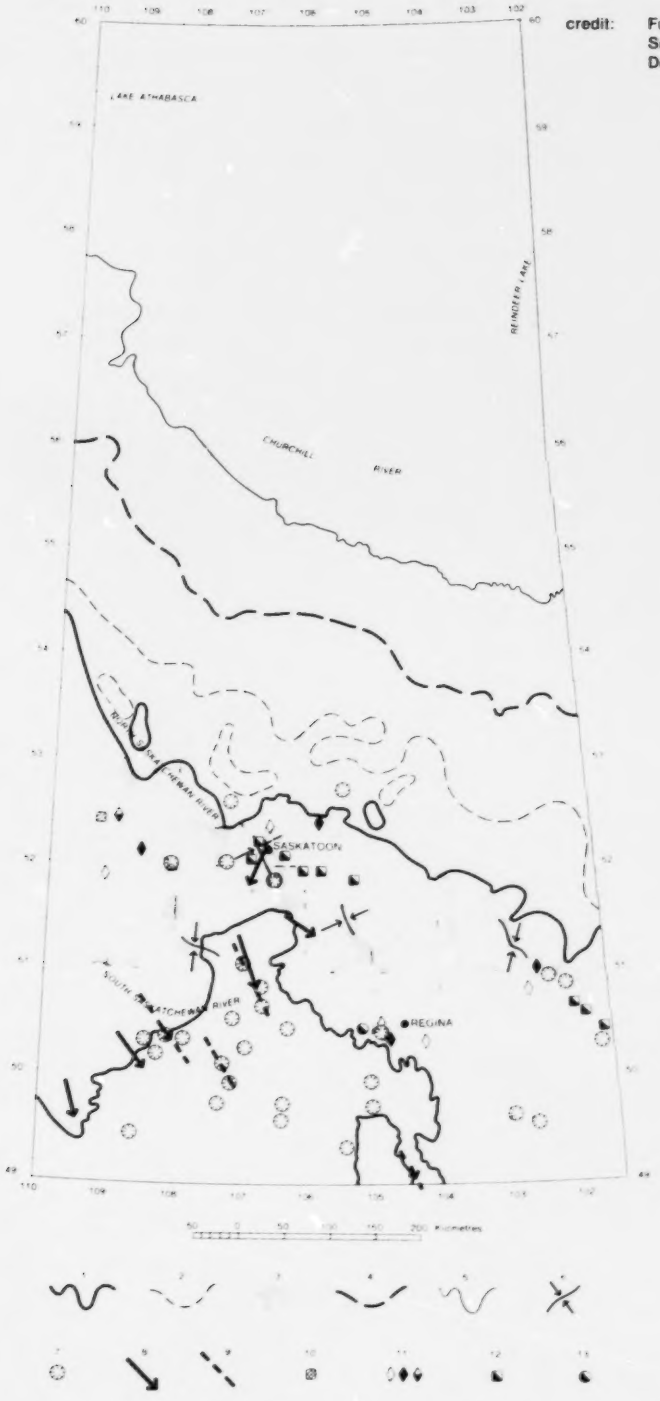

Figure 2—Cavern storage and mining operations in relation to solution-generated collapse features associated with the Prairie Evaporite (Middle Devonian). 1, edge of Prairie Evaporite salt ; 2, edge of Prairie Evaporite anhydrite; 3, local salt solution (seismic anomaly); 4, northern limit of Colorado (Cretaceous); 5, southern perimeter of Precambrian Shield; 6, linear solution features; 7, sinks and large-scale circular structures; 8, trend of known multistage salt-solution structures; 9, major seismic positive elements; 10, aquifer natural-gas storage; 11, LPG storage cavern, natural gas storage cavern, chemical plant facility; 12, shaft mining; 13, solution mining.

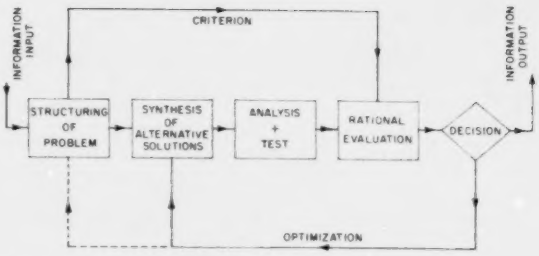

Figure 4—Model for system-design process.

(columns in Figure 5) with a view to summarizing the engineering parameters found to have been most favourable in a given geological setting.

Strata younger than the Devonian salt-bearing sequences are frequently seen to reflect controls of sedimentation by multistage salt solution and, in particular, by that associated with the Prairie Evaporite. This type of causal relationship lends itself to the extrapolation of solution-generated collapse features along trends, defined by younger depositional systems, allowing the safe siting of salt-cavern storage facilities at locations which are distant from such trends. A relationship with considerable promise in this regard is provided by spatial coincidence between local salt-solution features, associated with the Prairie Evaporite (Fuzesy, 1982) and the axes of Dina valley-fill deposits (Mannville Group, Lower Cretaceous) (Christopher, 1980). The importance of this relationship, shown in Figure 6, is underscored by the common practice of waste-brine disposal under high pressure into Mannville reservoirs, reported by Simpson and Dennison (1975).

Acknowledgments

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SYSTEM LIFE CYCLE		DESIGN PROCESS							
		COMPILATION OF INFORMATION	STRUCTURING OF PROBLEM	SYNTHESIS OF ALTERNATIVE SOLUTION	ANALYSIS + TESTS	EVALUATION	DECISION	OPTIMIZATION	COMMUNICATION + IMPLEMENTATION
PLANNING	CONCEPT FORMULATION								
	SYSTEM DEFINITION								
ACQUISITION	WATER SOURCE								
	WELL SITE								
	TARGET HORIZON								
	BRINING WELL								
	MONITORING DEVICE								
USE	OPERATION AND MAINTENANCE								
	ABANDONMENT + CONTINUED MONITORING								

Figure 5—Life cycle/design process matrix for the salt-cavern storage decision system.

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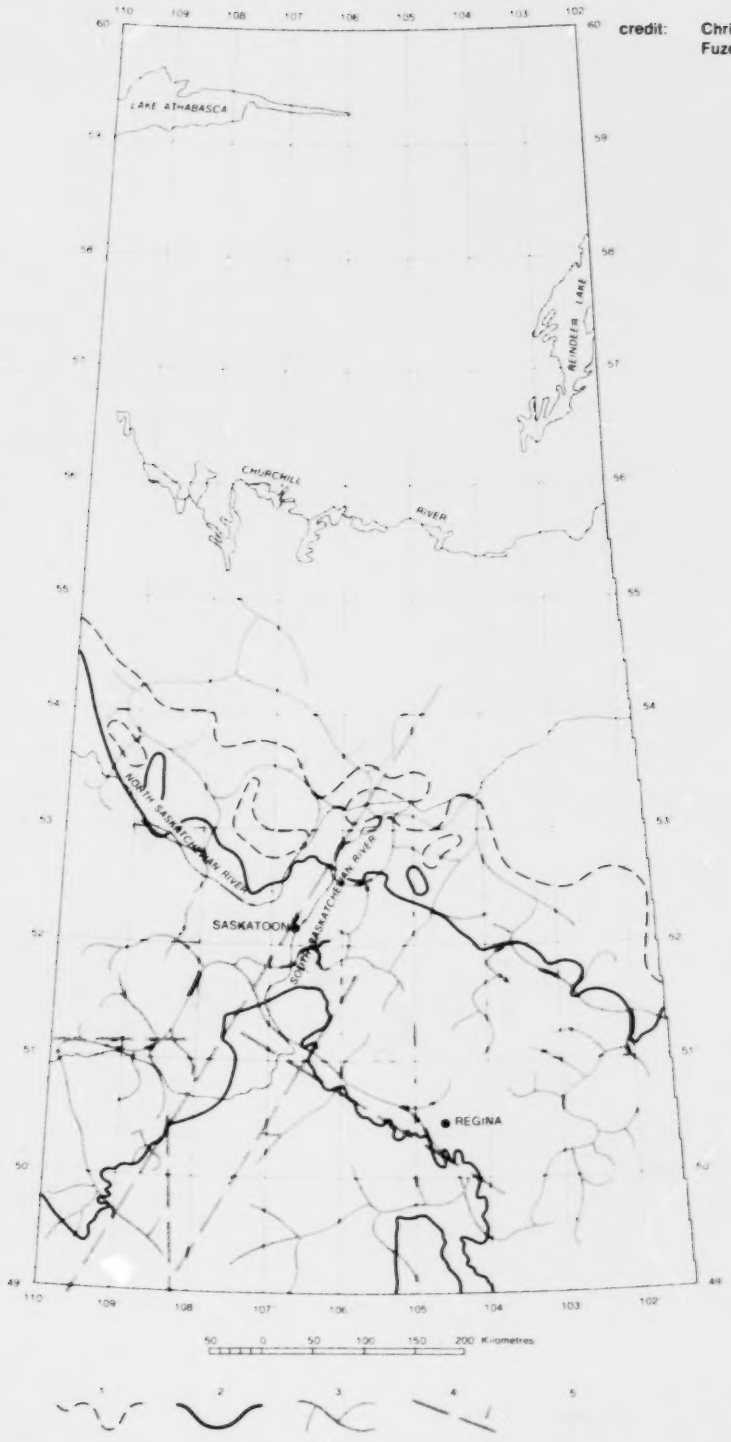

Figure 6—Solution-generated collapse features associated with the Prairie Evaporite (Middle Devonian) and axes of Dina (Lower Cretaceous) valley fill. 1, edge of Prairie Evaporite anhydrite; 2, edge of Prairie Evaporite salt; 3, axis of Dina valley fill; 4, structural linears; 5, local salt solution (seismic anomaly).

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Low-Permeability Gas Reservoirs in Marine Cretaceous Sandstones of Saskatchewan: 15. Notes on Origin, Mode of Occurrence and Probable Location of Undiscovered Gas Accumulations in Colorado and Montana Groups (Middle Albian to Campanian) of Southern Saskatchewan and Adjacent Areas

by Frank Simpson[1]

Although showings of natural gas have been recorded from sandstone and siltstone bodies of the dominantly argillaceous Colorado and Montana Groups in southern Saskatchewan, the only commercial gas production is in the southwestern and west-central parts of the province. This production comes from relatively few reservoirs of the Colorado and Montana Groups, by comparison to neighbouring parts of Alberta and Montana, and is mainly from the Milk River Formation, Medicine Hat Sandstone and Viking Formation and to a minor extent from the Ribstone Creek Tongue of the Belly River Formation. Small accumulations in the Phillips Sandstone (Second Specks Sandstone), St. Walburg Sandstone and Spinney Hill Sandstone are also under development. Exploration of multiple pay zones within the Colorado and Montana Groups of Saskatchewan also does not match that of southeastern Alberta and north-central Montana, either in the scale or in diversity of prospective producing units. In Saskatchewan production is restricted to comingled flow from the Milk River and Medicine Hat reservoirs of the Hatton district, which mark eastward extensions of major production trends in southeastern Alberta.

Origin of Natural Gas

Natural gas in the Colorado and Montana Groups of southern Saskatchewan generally contains more than 90 percent methane, relatively low percentages heavy hydrocarbons, up to 9 percent nitrogen and minor amounts of carbon dioxide. Hydrogen sulphide is commonly absent.

Similar gases with a high proportion of methane and relative enrichment in the light isotope C^{12} in the Upper Colorado succession and Montana Group of north-central Montana have been taken to indicate origin at shallow depths and relatively low temperature by breakdown of organic matter by anaerobic bacteria (Rice and Shurr, 1980). The source of natural gas was probably in the bituminous shales, calcareous shales and shaly chalks which envelope the low-permeability reservoir strata and are commonly intercalated with them.

Production from Low-Permeability and Conventional Reservoirs

The largely conventional oil and gas reservoirs of the Viking Formation in west-central Saskatchewan have type-IV sequence elements with permeabilities generally in the range 1 to 2 darcies, and type-III and -II elements with permeabilities of several hundred millidarcies. Markedly lower permeabilities characterize the producing type-III and -II elements of the Medicine Hat Sandstone in the Hatton field and the type-III elements of the Milk River Formation at Hatton and Liebenthal.

The depositional history of the Colorado and Montana Groups of Southern Saskatchewan was mainly controlled by differential movement of basement blocks, recognized by major northeasterly trending and minor northwesterly and northeasterly trending linear gravity anomalies (Simpson, 1979; this volume, Figure 1). The main structural control on the shallow-water marine sedimentation, giving rise to the producing strata of the Colorado and Montana Groups in western Saskatchewan, was the major Sweetgrass arch, which restricted the eastward dispersal of relatively coarse-grained siliciclastic debris. The role of smaller-scale basement linear features is less obvious, but gravity anomalies do delineate the northern and western limits of the Hatton field including the Medicine Hat Sandstone pool, and coincidence with an elevated basement block seems highly probable. The northeasterly and northwesterly deep-seated trends are also reflected in closely comparable solution features associated with the Middle Devonian Prairie Evaporite (Fig. 2). The trends of salt-solution structures are, moreover, important in the delineation of prospects outside of the areas of current production.

Similar deep structures have controlled the topographic relief of the sub-Cretaceous unconformity, producing pronounced variation in elevation and downcutting along erosional scarps into Jurassic, Mississippian and

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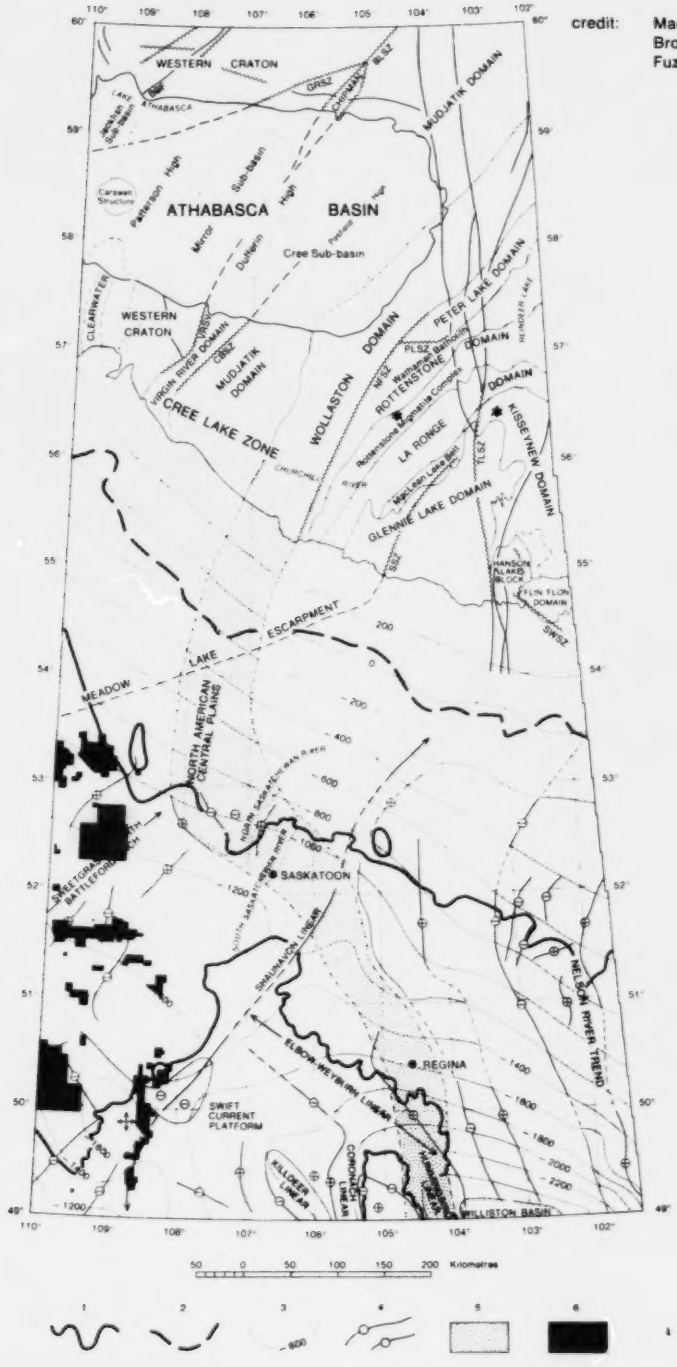

Figure 1—Basement features and edge of salt in the Prairie Evaporite (Middle Devonian) in relation to commercial hydrocarbon accumulations in Cretaceous strata of southern Saskatchewan. 1, edge of Prairie Evaporite salt; 2, northern limit of Colorado (Cretaceous) strata; 3, structure contours on Precambrian surface (CI # 200 m); 4, gravity gradient showing positive and negative margins; 5, conductive geomagnetic anomaly; 6, oil and gas fields.

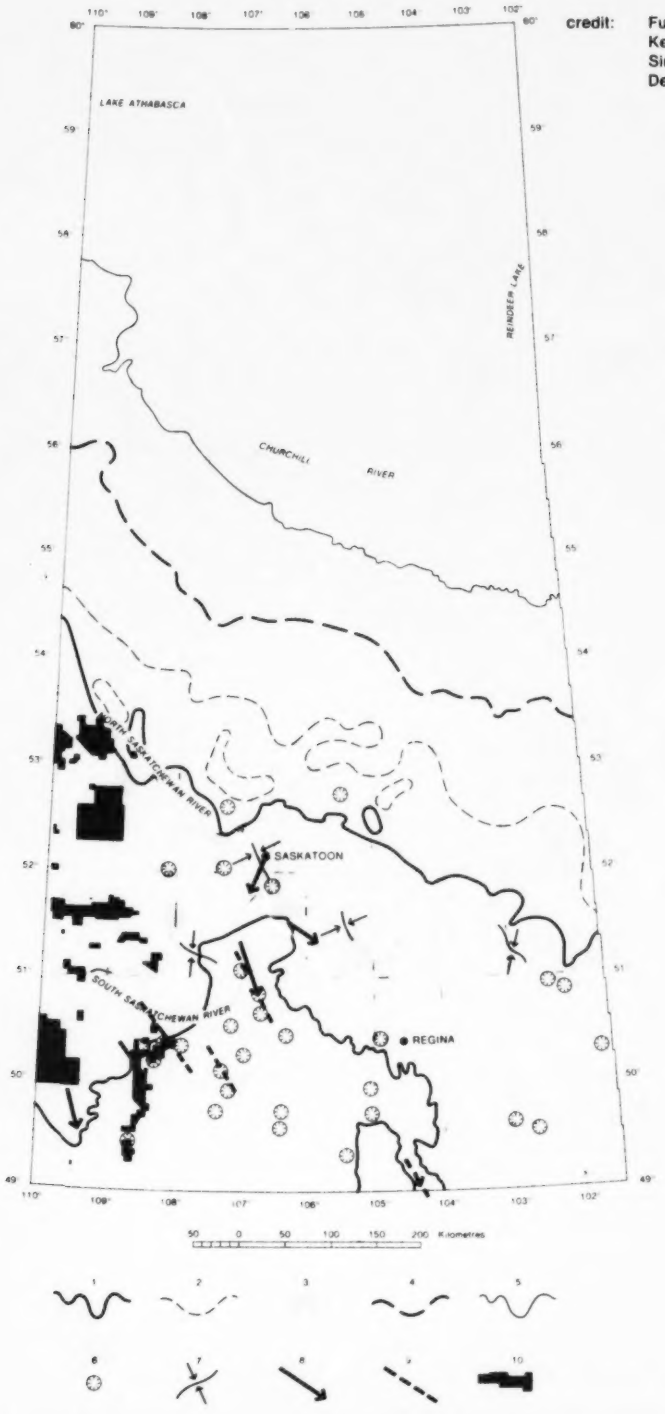

Figure 2—Solution-generated collapse features, associated with the Prairie Evaporite (Middle Devonian) in relation to commercial hydrocarbon accumulations in Cretaceous strata of southern Saskatchewan. 1, edge of Prairie Evaporite salt; 2, edge of Prairie Evaporite anhydrite; 3, local salt solution (seismic anomaly); 4, northern limit of Colorado (Cretaceous) strata; 5, southern perimeter of Precambrian Shield; 6, linear solution features; 7, sinks and large-scale circular structures; 8, trend of known multistage salt-solution structures; 9, major seismic positive elements; 10, oil and gas fields.

Devonian Units (Fig. 3). Compaction above the unconformity has produced irregular folds in the dominantly argillaceous marine strata. Low amplitude folds, for example, in the Viking reservoirs of the Dodsland-Hoosier district coincide with northeastward thinning and grain-size decrease in the producing unit. The Viking reservoir at Unity is located above the zero edge of the Upper Member of the Birdbear Formation.

Dickie and Williams (1973) showed that commercial accumulations of oil and gas in the Colorado and Montana Groups of southern and central Alberta tend to lie in belts trending northeast-southwest. Similar trends in some of the Viking reservoirs of west-central Saskatchewan may be due to orientation of reservoir strata parallel to the Viking shoreline. However, other fields extend at right angles to this trend and appear to reflect the influence of small-scale basement linear features. The Dodsland-Hoosier trend follows the erosional edge of Mississippian strata at the sub-Cretaceous unconformity. The Medicine Hat Sandstone and Milk River Formation reservoirs at Hatton are the continuation of a generalized northwesterly trend seen in southeastern Alberta.

Generalized Ranking of Natural-Gas Prospects

A generalized approach to the ranking of gas prospects considers (i) variation in reservoir quality, (ii) possible coincidence of facies belts with structural trends, (iii) known occurrence of natural gas as showings and as commercially sigificant pools in correlative strata, and (iv) depth below surface. These criteria are not listed in preferred order as they have different degrees of importance from one prospect type to another. Ten main prospects are now examined beginning with those judged to be of highest priority.

1. The Bow Island-Viking Succession of Southwestern and West-Central Saskatchewan. This unit is characterized by progressive northerly and northeasterly decrease in thickness and grain size across the area. Individual Bow Island sandstone bodies exhibit similar properties in the southwest. Type-II, -III, -IV and -V sequence elements are associated in upward-coarsening sequences in the southern and central parts of the prospective area, but tend to give way to type-II and -III elements to the north and east. The highest gas potential lies in the Hatton district, farther south and east towards the southern solution edge ofthe Prairie salt, and between the Jurassic and Mississippian erosional scarps of west-central Saskatchewan. In the Hatton district hydrocarbon accumulation in the Bow Island-Viking sequence of the Medicine Hat Sandstone and Mild River Formation is probably controlled by basement. Few showings have actually yet been recorded in the unit. Drape structures are common in the Viking Formation of west-central Saskatchewan and numerous showings of hydrocarbons exist between the main production locales. In the southwest, both conventional and low-permeability reservoirs occur at depths of over 1000 m and are the deepest prospects considered.

2. The Viking-Newcastle succession of Southeastern Saskatchewan. In the south-central part of the area the unit is made up of upward-fining and subordinate, upward-coarsening sequences, forming multistorey sandstone bodies which tend to pinch out to the west and east. Type-II, -III and -IV sequence elements commonly occur together, although a dominance of shaly type-III elements appears to be fairly widespread. Showings of hydrocarbons are relatively common and sites of coincidence between basement linear features and solution-generated collapse associated with the Prairie Evaporite may provide the most favourable drilling locations. The drilling depths of prospects may be expected to lie in the range 800-1000 m.

3. The Milk River Formation of Southwestern Saskatchewan. The succession is composed largely of shaly sandstones and siltstones, in the form of type-III elements. The Middle Unit and the uppermost sandy strata of the Lower Unit are regarded as being most prospective for natural gas. The most favourable area for drilling is considered to be in the extreme southwest of the province, south of the Hatton district, at locations where the dominant northerly strike of structure contours at the base of the Upper Colorado succession and the top of the Milk River Formation is disrupted by minor east-west deflections probably reflecting basement influences. The area between Hatton and Liebenthal is also regarded as prospective for gas.

4. The Phillips Sandstone and Bowdoin Sandstone of Southwestern and South-Central Sakatchewan. The Phillips Sandstone is composed mainly of type-II sequence elements, although scarce type-III elements also occur in extreme southwestern locations. Upward-coarsening sequences defined by progressive upward decrease in the proportion of intercalated mudstone are common. The Bowdoin Sandstone appears to be made up of type-II elements only. Both units progressively decrease in grain size northwards. The rationale underlying exploration for Phillips Sandstone reservoirs south of Hatton is similar to that outlined

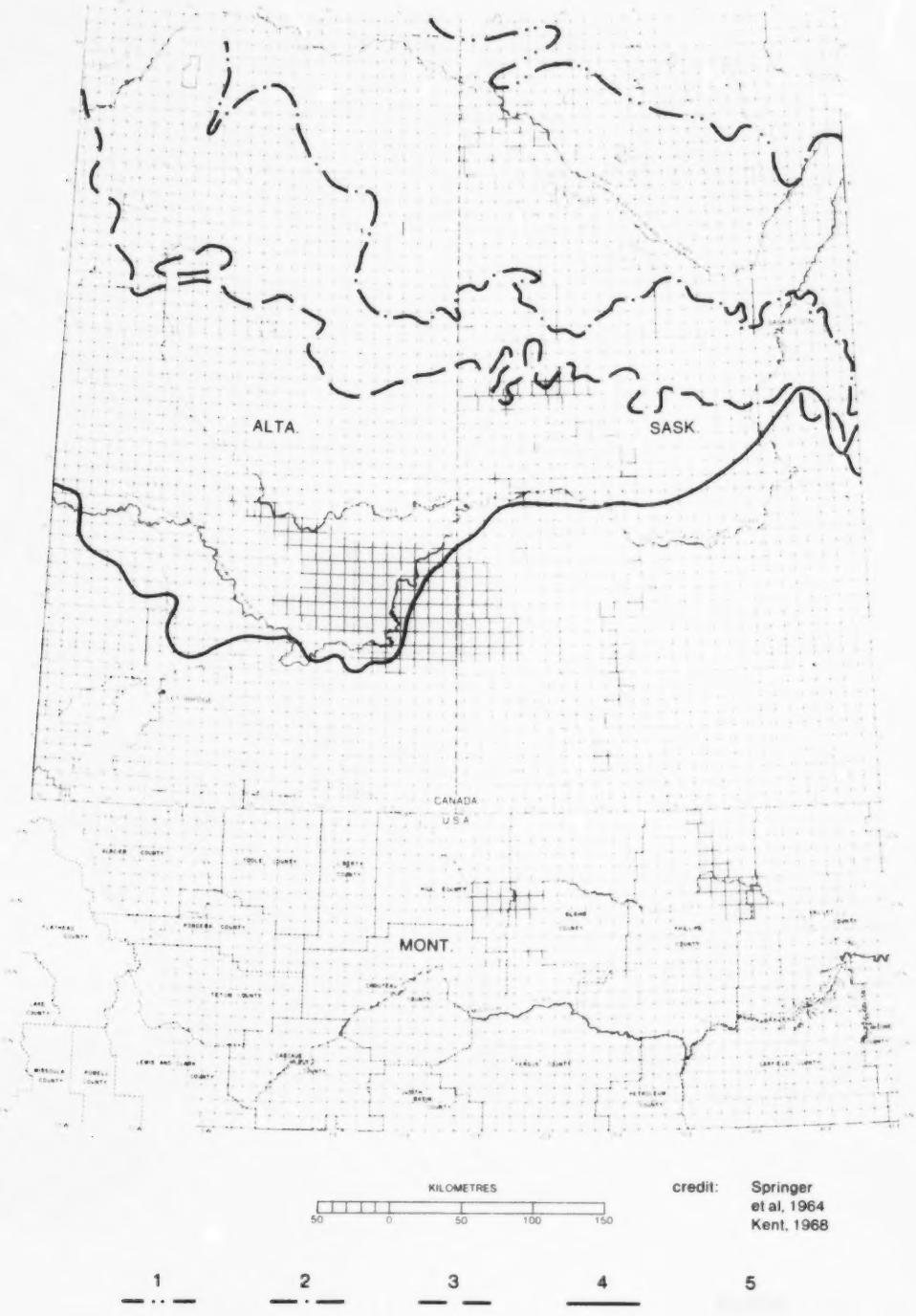

Figure 3—Erosional edges of Devonian, Mississippian and Jurassic strata in relation to commercial hydrocarbon accumulations in Cretaceous strata of southern Saskatchewan. 1, edge of Saskatoon Member (Duperow Formation); 2, edge of Upper Member of Birdbear Formation; 3, edge of Mississippian strata; 4, edge of Jurassic strata; 5, oil and gas fields.

for the Milk River Formation. The Bowdoin Sandstone is likely to take on increased importance in south-central Saskatchewan, particularly to the immediate north of the Bowdoin field of north-central Montana.

5. The Medicine Hat Sandstone of Southwestern Saskatchewan. The Medicine Hat Sandstone consists of type-III and type-II elements, arranged in dominantly upward-coarsening sequences. The most prospective area for natural gas in the unit is to the immediate south of the Hatton field.

6. The Ribstone Creek Tongue of the Belly River Formation in Southwest and South-Central Saskatchewan. The Ribstone Creek Tongue and other Belly River subdivisions are seen as type-II, -III and -IV sequence elements and are prospective for natural gas at locations considered favourable for Milk River and Upper Colorado reservoirs.

7. The Spinney Hill Sandstone of West-Central Saskatchewan. The Spinney Hill Sandstone is made up of type-II, -III and -IV elements, arranged in repeated upward-fining sequences in west-central Saskatchewan. The eastern part of the Dodsland-Hoosier production district is regarded as prospective for Spinney Hill gas. Farther west the unit undergoes progressive increase in intercalated shale.

8. The St. Walburg Sandstone of West-Central Saskatchewan. The unit consists of type-II and -III sequence elements in generalized upward-coarsening sequences, which decrease pronouncedly in thickness and grain size to the west and south. The most prospective locations are in the vicinity of the Meadow Lake escarpment, near the Fourth Meridian.

9. The Fish-Scale Sandstone of Southwestern Saskatchewan. The Fish-Scale Sandstone and associated Lower Colorado strata are composed of type-II sequence elements and may be regarded as prospective for hydrocarbons at locations considered favourable for Milk River and Upper Colorado reservoirs.

10. The Shaly Chalks and Calcareous Shales of the Upper Colorado Succession in Southwestern Saskatchewan. These rocks are made up of type-I and type-II sequence elements, with the relatively coarse-grained layers composed of pelecypod debris, foraminiferal tests and other fragments in a chalk matrix. The most prospective areas are likely to be those highlighted for the Milk River and Upper Colorado successions. At these locations the First White-Speckled Shale and the Greenhorn Lime should also be tested. The latter unit may be prospective in south-central Saskatchewan to the north of the Bowdoin field.

Acknowledgemnts

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INDUSTRIAL MINERALS INVESTIGATIONS

Fuel Peat Potential in the La Ronge Region

by R. Troyer

The Saskatchewan peat study was initiated on a modest scale in 1974/75 by Saskatchewan Mineral Resources partially in response to an increasing number of inquiries about agricultural peat and peat as a source of energy. Initial investigations by the department concentrated on the Carrot River/Hudson Bay area. During these studies it became apparent that central Saskatchewan possessed numerous extensive peatland areas for which there was little physical or chemical data. A reconnaissance peat resource program was initiated in 1976 to assess the distribution, quantity and quality of the fuel and moss peat resources contained in a 200 km wide belt on the Phanerozoic strata adjacent to the southern edge of the Precambrian Shield, as outlined on the accompanying map (Fig. 1). Some deposits of significant quality and size favourably disposed to transportation facilities and potential markets were examined in greater detail. Of secondary interest was the evaluation of promising deposits in terms of technical and economic feasibility of development and utilization. The high and increasing cost of conventional energy sources, particularly in the remote towns in central Saskatchewan, stimulated this investigation into an alternative fuel supply.

In 1979, over 330 peatlands were sampled in the La Loche/Buffalo Narrows/Ile-a-la-Crosse/ Beauval region (Fig. 2). Analyses were performed on samples obtained from 150 of the 330 peatlands (Troyer, 1979).

In 1980, 169 peatlands were investigated and sampled in the Pinehouse/La Ronge/Weyakwin region (Fig. 2). Selected samples, totalling 46, were analyzed by the Saskatchewan Research Council for fuel peat quality (Troyer, 1980; Guliov and Troyer, 1981).

In late 1980, the Buffalo Narrows Demonstration Project was initiated (Guliov and Troyer, 1981) when Saskmont Engineering was contracted to investigate the economic viability of fuel peat (and moss peat) production and utilization in the Buffalo Narrows area, including costs of distribution and conversion of existing heating systems. In the fall of 1981, the practical Demonstration Project commenced and is expected to continue until mid-1983 (see report by P. Guliov, this volume).

The present report deals with work completed during the summer of 1982. Saskatchewan Energy and Mines, with contractual assistance from Saskmont Engineering, studied 43 previously selected (by aerial photograph interpretation) peatlands within 100 km of La Ronge for their fuel peat potential. Considering drainability, location, accessibility, tree cover and time available for the study, these were narrowed by helicopter reconnaissance and ground proofing to three deposits upon which semi-detailed survey and sampling were carried out (Fig. 3). The purpose of the 1982 project was to locate sufficient economically favorable fuel

Figure 2—Peat resource survey areas.

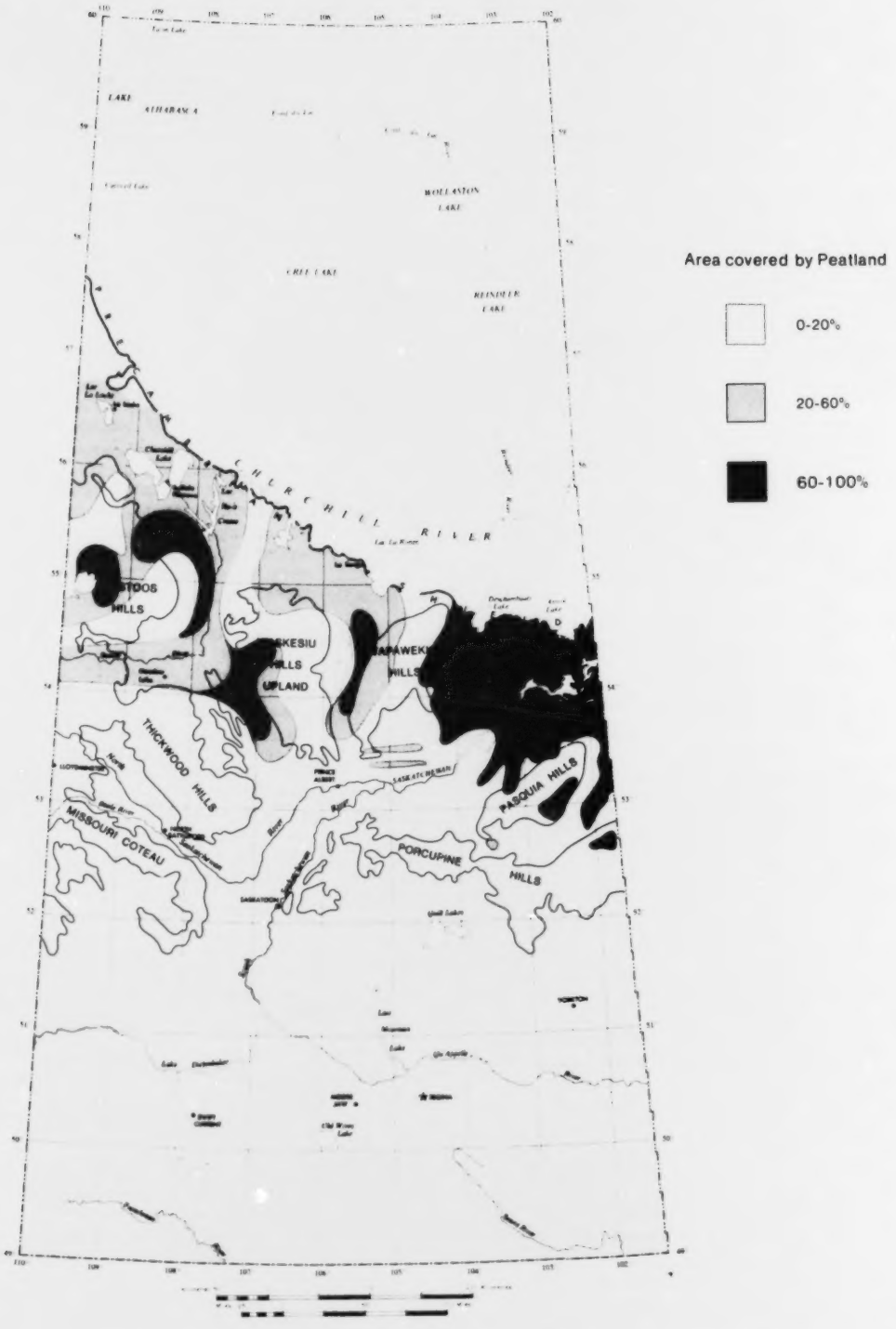

Figure 1—Potential peat areas of Saskatchewan south of the Precambrian Shield.

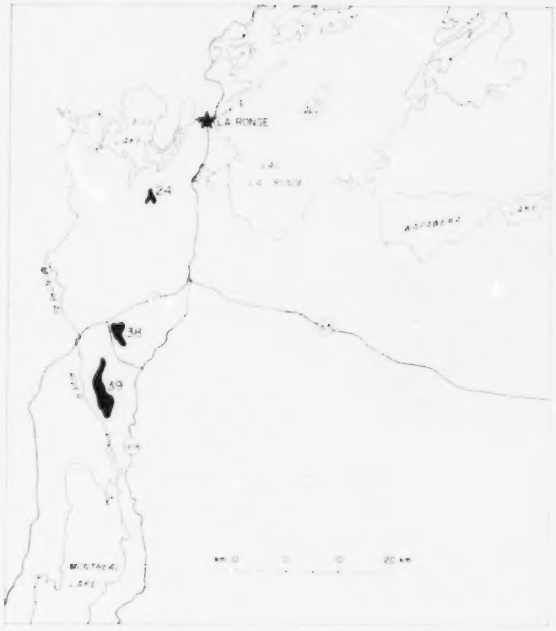

Figure 3—Location of peat deposits surveyed in 1982.

peat areas to assure a minimum of 25 years reserve of domestic fuel for La Ronge, as well as to determine the existence of suitable reserves for small- to medium-scale industry (eg. power plant, briquetting plant, pelletizing plant, coking plant, gasification plant).

Methods of Study

The detailed survey technique for the 1982 season varied slightly from earlier work. As a result of time and budget restraints, only one line was traversed down the long axis of each peatland, with stations every 100 metres. The pacing was more accurate than in earlier years as a line counter was used. Peat classification and depth soundings alternated every 100 m until persistent readings of less than 1.0 m of peat were recorded. Classification data include bog type, cover type, peat thickness, subsoil type, occurrence of permafrost, depth variation of peat type, humification (Table 1), water, fibre and wood content, and any other pertinent data. This information was utilized in the deposit descriptions, in the construction of isopach maps, humification and peat type profiles and in the estimation of peat quantities.

Volume and tonnage figures for the deposits were obtained as follows:

a) Volumes: Volume (m^3) = average thickness (m) x area (ha) x 10,000 (m^2/ha)

The area with < 1.0 m of peat was assumed to have an average 0.5 m, while the area with ≥ 1.0 m of peat were averaged.

Table 1 - Von Post Degree of Humification.

Degree of Humification — von Post's Scale	Description
H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.
H2	Almost completely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but for which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains slightly pasty and has lost some of the identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very "muddy" water with also a very small amount of amorphous granular peat escaping between the fingers. The structure of plant remains is quite indistinct, although it is still possible to recognize certain features. The residue is strongly pasty.
H6	Moderately strongly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is strongly pasty but shows the plant structure more distinctly than before squeezing.
H7	Strongly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very strongly decomposed peat with a large quantity of amorphous material and very dry indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
H9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed, almost all of the peat escapes between the fingers as a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

b) Tonnages: Tonnage = average thickness of peat of 1.0 m x area(ha) x 1460(tonnes of dry matter/m-ha)

The figure 1460 tonnes/m-ha is derived from bulk density measurements of Buffalo Narrows fuel peat.

To determine tonnages at 50 percent moisture content (M.C. at which milled fuel peat is delivered for briquetting and power generation) the tonnage quantity calculated must be doubled. In so doing, it is assumed M.C. and weight are linear.

To determine tonnages at 35 percent moisture content (M.C. at which fuel peat sods are delivered for domestic heating and coke/briquetting) the factor of 1.54 must be applied to the tonnage quantity.

To produce a 'useable' tonnage figure the average thickness of the slightly humified surface layer (H1-3) and the basal 0.5 m of peat (due to mineral soil contamination) must be discounted.

Economic potential figures were calculated as follows:

a) by multiplying the area (ha) of each bog by 160T/ha/yr (estimated yield of milled peat at 50 percent M.C.)or 115T/ha/yr (estimated yield of sod peat at 35 percent M.C.), depending on the type of peat material required for specific uses, to obtain the tonnage per year each deposit could supply and therefore the processes each deposit could support;
b) by dividing the total tonnage in each deposit by the processes' annual requirements to obtain the production life for each process supported by that deposit; and
c) by dividing the annual requirement by the annual production per hectare to obtain the minimum bog size for each process.

Samples, taken at the mid-point of each traverse line and at 0.5 m intervals (until mineral soil was encountered), were stored in labelled plastic tube-bags.

Analyses for energy peat (moisture content, ash, volatile matter and fixed carbon, calorific value, carbon, hydrogen, nitrogen, oxygen, sulphur and pH) were performed by the Saskatchewan Research Council utilizing modified ASTM analytical procedures. Radiocarbon dates obtained from the three deposits were also completed by the SRC.

Peatland Descriptions

Peatland No. 24:

Peatland no. 24 (Fig. 4), accessible by a winter road cutting its northern tip, is located approximately 5-6 km west of Highway 2 and 15 km southwest of La Ronge. The winter road forms a good access route for any possible future commercial development.

The study area of peatland no. 24 is 212 ha, only a fraction of the 320 ha deposit. It is a contiguous part of peatland no. 25, an 800 ha deposit to the east. A 2.2 km survey line, extending along the long axis of the deposit, reveals an average thickness of 2.6 m over an area of 150 ha, with a maximum of 5.0 m (Fig. 4).

The majority of the deposit is marked by strings (ridges) and flashets, signs of a string bog. It is generally tree-covered with the cover varying from small open flashets in the central part of the peatland to a 60 percent tree cover in the northern end (ie. considerable tree clearing would be

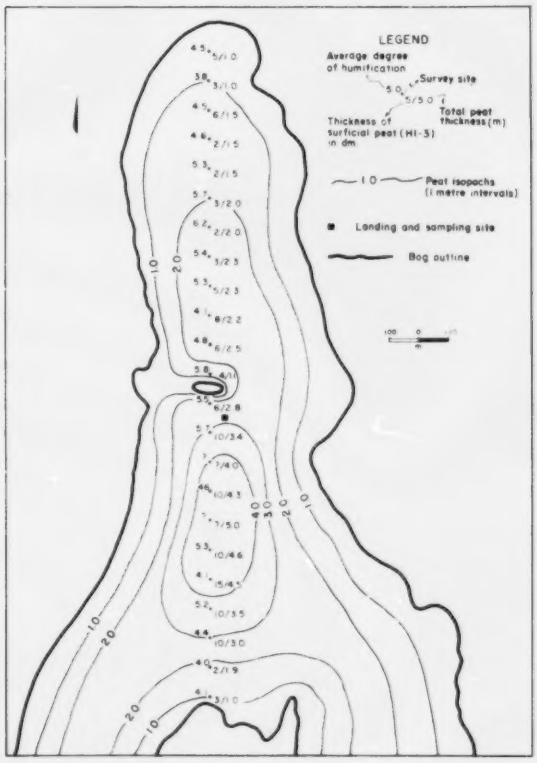

Figure 4 – Peatland No. 24: isopach map.

required for commercial use). The Radforth cover classification (Table 2) in the flashets is primarily FI and EFI, while on the strings it varies from EFI to BEF. In the northern part of the bog, "A" class becomes predominant. Eutrophic fen vegetation dominates the flashets, while the strings are inhabited by mesotrophic bog vegetation in most locations and oligotrophic in a few areas. On the whole, the bog is mesotrophic-eutrophic.

The surface peat, predominantly sphagnum, averages about 0.3 m in thickness. Sphagnum peat types comprise approximately 13.5 percent of the total peat. The remaining 86.5 percent of the peat is of sedge and woody sedge. The humification and peat type profiles (Fig. 5a and 5b) illustrate that all of the H4 peat (76 percent of the deposit) is of sedge type and therefore useable as a fuel.

The drainability of the bog can only be generally assessed without accurate elevation measurements. The parallel ridges evident in the bog indicate the presence of a drainage gradient (perpendicular to the ridge pattern) toward the north end of the deposit from where a small creek drains into a lake 2-3 km north.

The total volume of peat in the deposit is 4.21 million m^3, of which 0.31 million m^3 is in the 62 ha less than 1.0 m thick and 3.90 million m^3 is in the 150 ha greater than or equal to 1.0 m thick. The tonnage figures are 569,500 tonnes (dry matter), 1.14 million tonnes (at 50 percent M.C.), and 657,000 "useable" tonnes (at 50 percent M.C.). If the thickness and area calculations are extrapolated to include deposit no. 25, the useable tonnage figure increases to 3.5 million tonnes (at 50 percent M.C.).

Peatland No. 38:

Peatland no. 38 is located 55 km south of La Ronge and approximately 1-2 km south of Highway 2. Good access to the deposit is provided by a number of logging roads in the vicinity, one of which bisects the northern tip. These logging roads also service peatland no. 39.

The deposit is approximately 530 ha in area (Fig. 6) of which 295 ha are $\geq$ 1 m thick. A 3.6 km survey line along the long axis of the bog reveals a thickness range of 1.0 to 3.5 m, and an average of 1.9 m. This average is low, however, due to the shallow southern end of the bog and to the survey line segment which passes in close proximity to mineral islands. These factors have resulted in a preliminary under-estimation of the total resource which a more dense network of survey lines would most likely correct.

The southern part of the deposit is a meadow-like sedge-covered eutrophic fen with a very high water table. The northern area shows more oligotrophic features and is basically a tree-covered bog with "B" cover class and abundant sphagnum mounds. The Radforth cover classification for the fen area is predominantly FI with minor EIF islands and scattered dead "B" class.

Table 2. Summary of Properties Designating nine pure coverage classes (From Radforth, 1952)

Coverage Type (Class)	Woodiness vs. Non-woodiness	Stature (approx. height)	Texture	Growth Habit	Example
A	woody	15 ft or over	-	tree form	Spruce Larch
B	woody	5 to 15 ft	-	young or dwarfed tree or bush	Spruce, Larch, Willow, Birch
C	non-woody	2 to 5 ft	-	tall grass-like	grasses
D	woody	2 to 5 ft	-	tall shrub or very dwarfed tree	Willow, Birch Labrador tea
E	woody	0 to 2 ft	-	low shrub	Blueberry Laurel
F	non-woody	0 to 2 ft	-	mats, clumps or patches sometimes touching	Sedges, Grasses
G	non-woody	0 to 2 ft	-	singly or loose association	Orchid
H	non-woody	0 to 4 in	leathery to crisp	mostly continuous mats	Lichens
I	non-woody	0 to 4 in	soft or velvety	often continuous mats sometimes in hummocks	Mosses

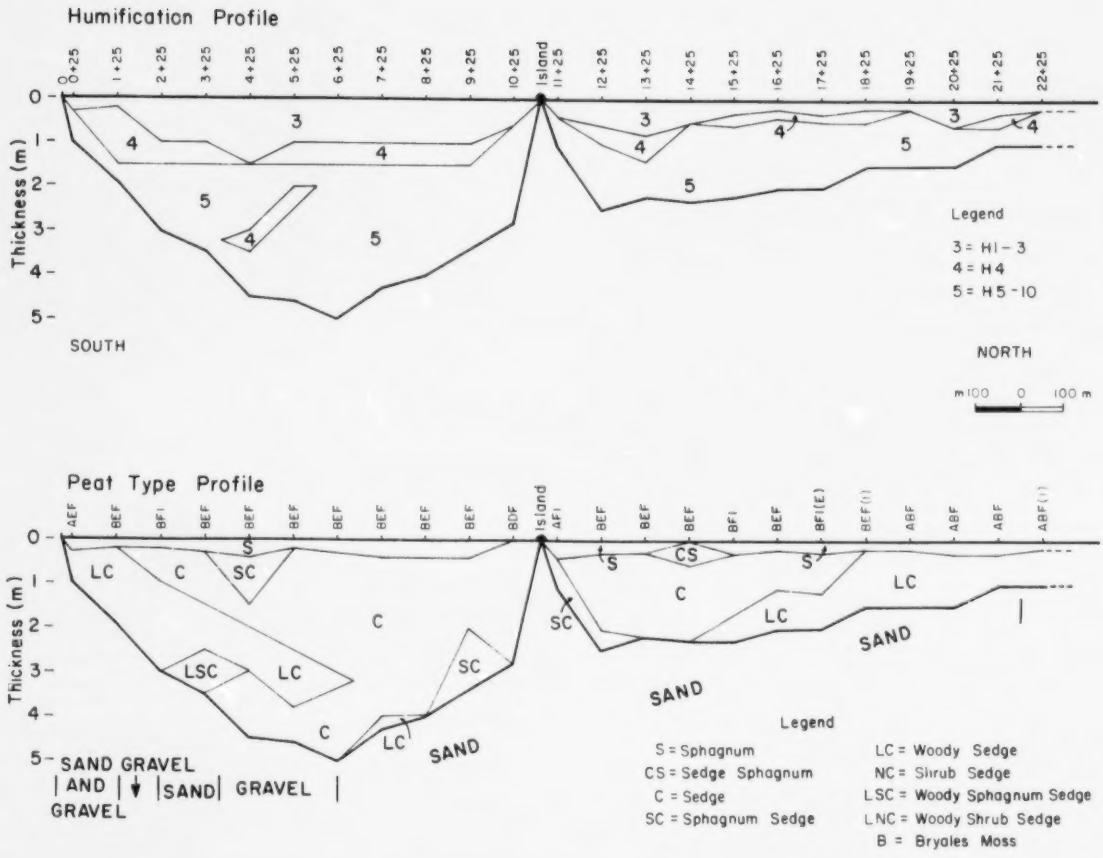

Figure 5—Peatland No. 24: humification and peat type profiles showing cover formulae and mineral subsoil type.

Northward the cover gradually changes from EFI to BFI to BEF and finally to BEI at the northernmost end.

The surface layer (H1-3) of peat varies in thickness from 0.4 to 1.5 m, averaging 0.9 m, and constitutes 47 percent of the deposit (Fig. 7a). The surface peat is predominantly sphagnum-sedge with some sedge-sphagnum in the fen area, and sphagnum with sphagnum-sedge in the bog area (Fig. 7b).

The majority of the deposit is divided between sedge and woody-sedge peat with a thin lenses of sphagnum-sedge forming the basal layer (Fig. 7b). Peat type proportions show 7 percent sphagnum types and 93 percent sedge types (39 percent sedge, 29 percent sphagnum sedge, 21 percent woody sedge and 4 percent other sedge types). All the peat with a humification of H4 or more (53 percent of the deposit, Fig. 7a) is of sedge type and thus fuel peat. The average humification for the deposit is 3.8, low because of the shallow south end and the presence of the thick surface layer.

Drainability determinations are difficult without surface elevation measurements. However, from air photo interpretation, the bog appears drainable to the east-northeast, into the Highway River system.

The total volume of bog no. 38 is 6.87 million m^3 of which 5.59 million m^3 occurs in the 295 ha greater than or equal to 1.0 m in thickness. The tonnage figures for the same area (295 ha) are 820,000 tonnes (dry matter), 1.64 million tonnes (at 50 percent M.C.) and 430,000 "useable" tonnes (at 50 percent M.C.).

Peatland No. 39:

Peatland no. 39 is located 60 km south of La Ronge and 7 km west of Highway 169. Access, to within 1 or 2 km of the peatland, is

Figure 6—Peatland No. 38: isopach Map (refer to Fig. 4 for legend).

available by a winter road at the southern end and a number of logging roads to the east.

The total area of peatland no. 39 is approximately 2400 ha with the surveyed portion approaching 900 ha in area. The survey line of 7400 m is located down the long axis of this area and reveals an average depth of 2.7 m, with a maximum of 4.3 m (Fig. 8). Deposit no. 39 is a member of a large peatland network.

Most of the deposit is a string bog of alternating flashets, with eutrophic fen vegetation and strings with mesotrophic bog vegetation. Large areas of the deposit,

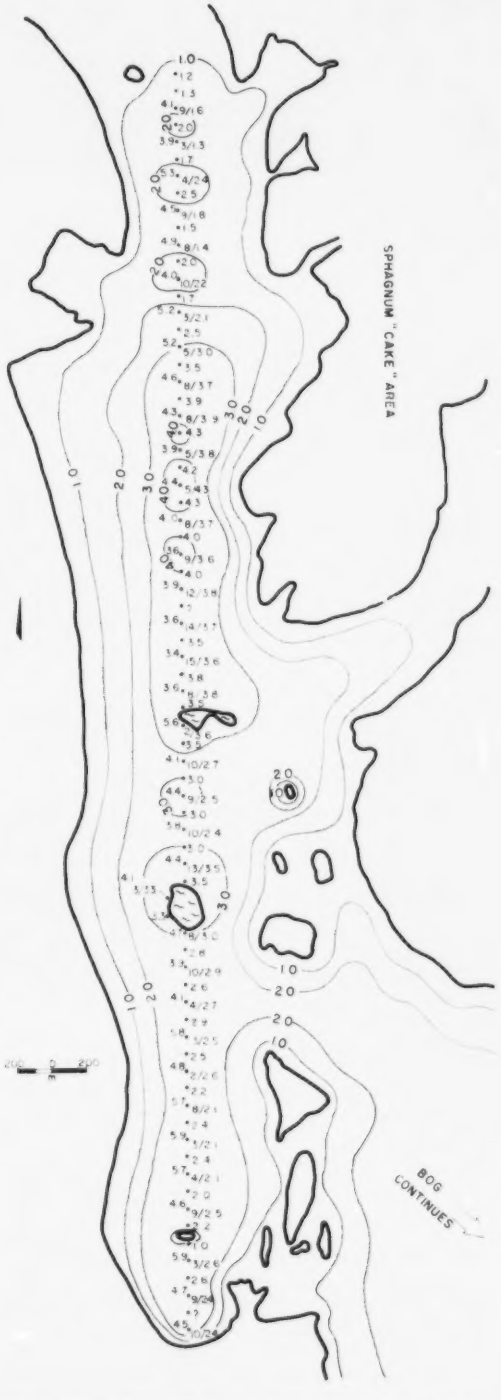

Figure 8—Peatland No. 39: isopach map (refer to Fig. 4 for legend).

especially the northern section, have prominent 40 to 60 cm thick sphagnum mounds covering up to 90 percent of the surface

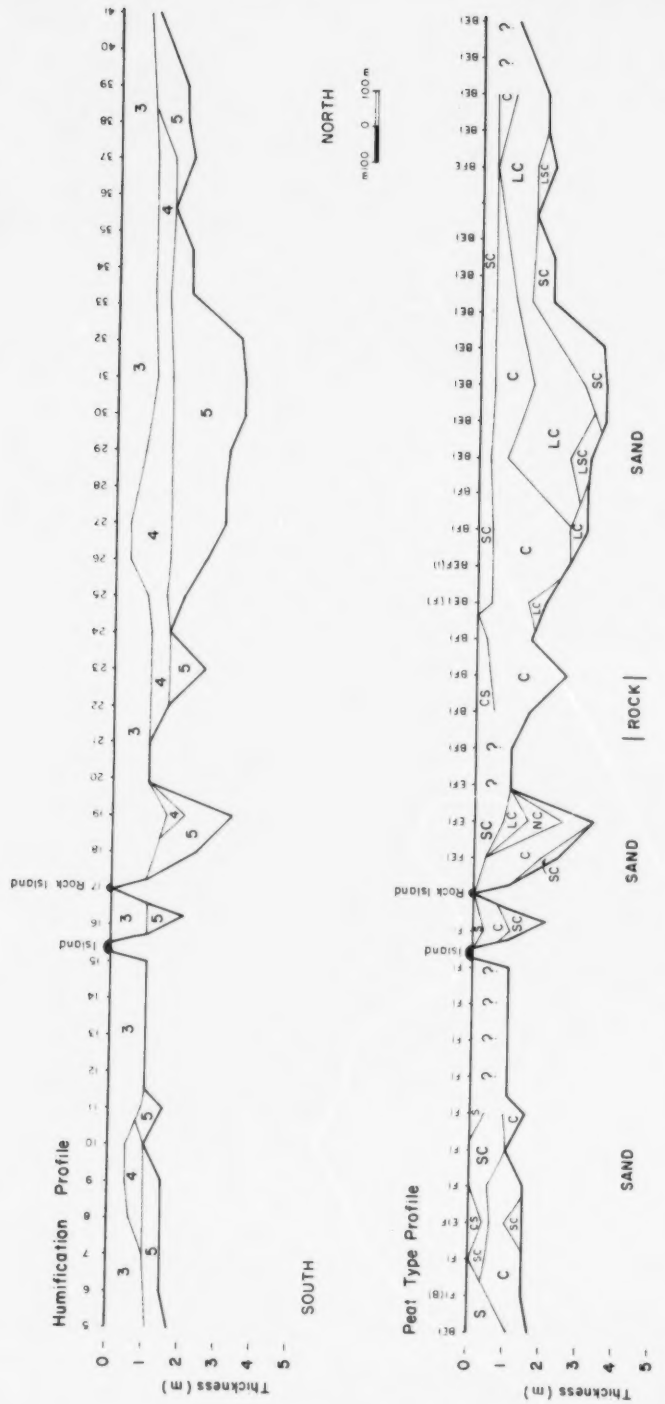

Figure 7—Peatland No. 38: humification and peat type profiles showing cover formulae and mineral subsoil type (refer to Fig. 5 for legends).

area. The surface cover is composed of 10 percent "B" class with a rapid increase from 10 to 30 percent in the northernmost 500 m. In this northern area the trees are healthy and form a dense cover, shadowing up to 30 percent of the bog surface under their canopies. In a large area, the "B" cover is fire-killed. The most common cover is BEI with scattered DEI and DFI. In the flashets, there are also small areas of FI and GI cover. As a whole the deposit is a complex of fen-bog types with the fen types predominant.

The peat types present are very uniform with sedge (55 percent), woody sedge (18 percent) and sphagnum sedge (12 percent) the most common (Fig. 10). The sphagnum peat types, accounting for only 12 percent of the total, are the dominant surface layer. Sphagnum-sedge peat occurs as a thin bed beneath the surficial layer and as intermittent lenses at the base of the deposit. The majority of the peatland is sedge with minor occurrences of woody sedge, except in the northern 1000 m where woody sedge is predominant. The degree of humification is generally quite high, averaging H4.6 (Fig. 10). The surface layer (H1-3) varies from 0.2 to 1.5 m, averaging 0.75 m. Due to the high percentage of sedge, all the peats with H4 or higher (74 percent of the total) are fuel peats.

Drainage to the south into the Montreal River appears to be possible, as indicated by the existence of strings defining the presence of a gradient.

The total volume of the 900 ha surveyed is 19.5 million m^3, 18.4 million m^3 of which are in the 680 ha area greater than or equal to 1.0 m thick. The tonnage figures for this 680 ha are 2.68 million tonnes (dry matter), 5.36 million tonnes (at 50 percent M.C.) and 2.98 million "useable" tonnes (at 50 percent M.C.). If the calculations are extrapolated to cover the whole 2400 ha complex then the

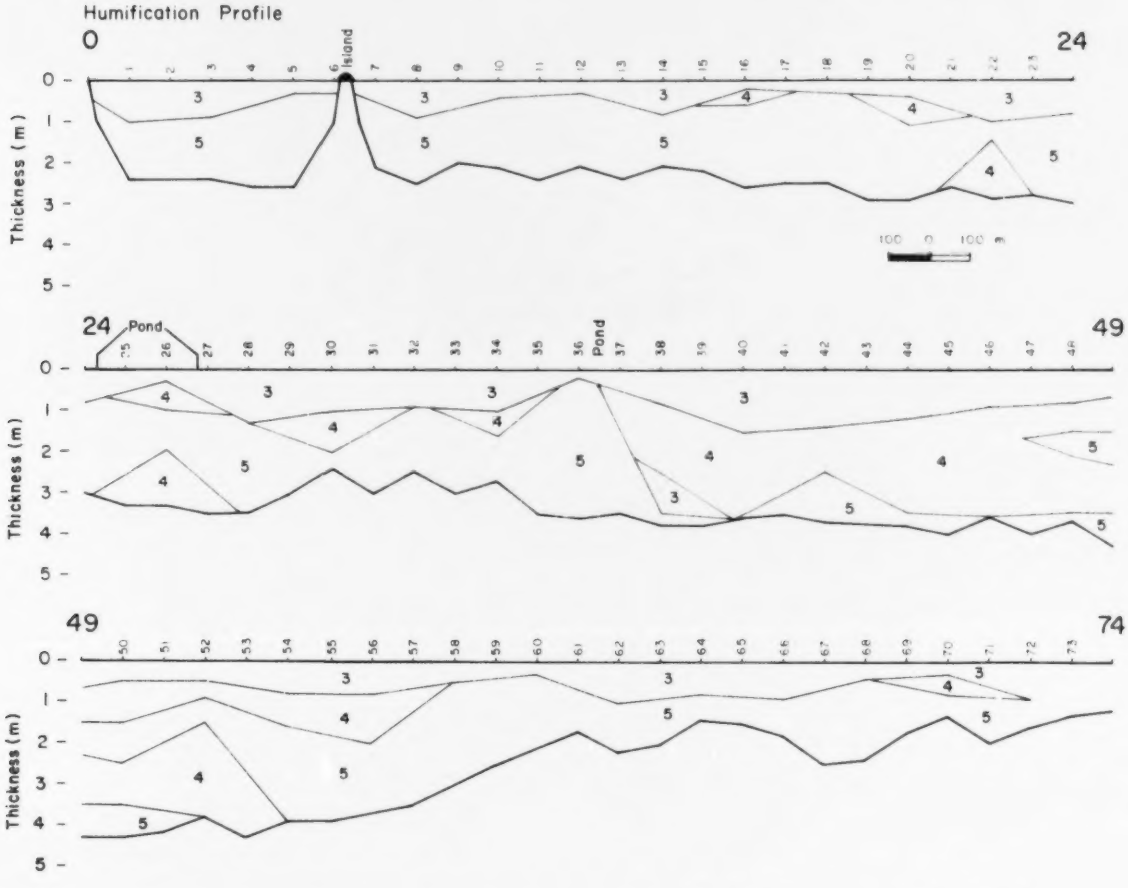

Figure 9—Peatland No. 39: continuous humification profile, south end at top left, north end at bottom right (refer to Fig. 5a for legend).

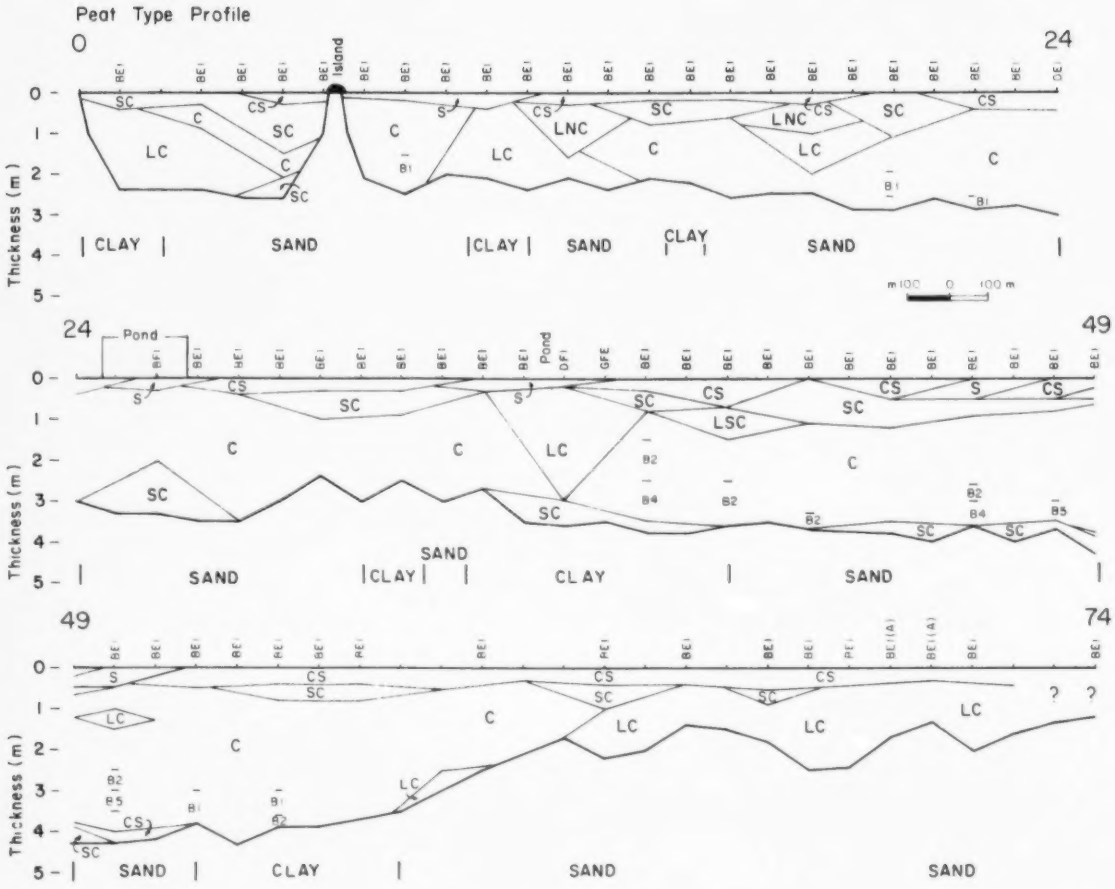

Figure 10—Peatland No. 39: continuous peat type profile, south end at top left, north end at bottom right (refer to Fig. 5b for legend).

total volume is 49 million m^3 and the "useable" tonnes approach 7.95 million.

Economic Potential

As described in the previous section, the 1982 field survey has revealed the presence of abundant fuel peat resources in the La Ronge area. The peat types, degree of humification, peat thickness and quantity, drainability, access and close proximity to the La Ronge market enhance the economic potential of the surveyed deposits. Comprehensive detailed field surveys of these and other deposits in the region are warranted if market interest can be demonstrated.

Four peat processes have been selected for the peat deposits of the La Ronge area from a large number of possible applications: domestic or district heating (conversion costs for district heating in an existing community are too high for it to be considered), a 50,000 T/yr. briquetting plant, a 50,000 T/yr. coke/briquetting plant, and/or a thermal power generating station. These selected processes reflect the deposit size and ability to supply the required annual amount of raw material. The potential markets, transportation costs, initial production costs, and potential product demand within the region, as well as distant markets for any residual product from local consumers, will determine whether a fuel peat industry is initiated.

The requirements of the four processes are listed in Table 3. Combining these figures with the size and quantity data of the three bogs studied, the type of utilization and the number of production years can be calculated for each deposit (Table 4).

Table 3 - Size and Tonnage Requirements of Four Selected Peat Processes.

Potential Use	Raw Material Required (T/yr)	Minimum Peat-land Size Required (ha)	Tonnes/25 year Production Life
Domestic Heating (based on 1100 home units)	11,000 (sods at 35% M.C.)	100	275,000
Briquetting Plant (50,000 T/yr)	100,000 (milled at 50% M.C.)	670	2.5×10^6
Coke/Briquetting Plant (50,000 T/yr)	150,000 (sods at 35% M.C.)	1300	3.75×10^6
Thermal Power Generation	25 MW-200,000 40 MW-400,000 (milled at 50% M.C.)	1250 2500	5.0×10^6 10.0×10^6

Table 4 - Potential Uses and Production Years for the deposits surveyed in 1982.

Bog No.	Possible Uses	Production Years
24	domestic heating	46
24+25	a) domestic heating	245
	b) briquetting plant	34
38	domestic heating	30
39	a) domestic heating	270
	b) briquetting plant	30
39 complex	a) domestic heating	720
	b) briquetting plant	80
	c) coke/briquetting plant	53
	d) 25 MW power station	40
all deposits combined	a) any of the above	> 50 yrs (depending on use)
	b) 40 MW power station	approx. 25

Tables 3 and 4 indicate that the La Ronge area possesses sufficient resources for domestic as well as commercial applications of fuel peat for decades to come.

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Fuel Peat Demonstration Project

by P. Guliov

This project commenced during 1981 following an approval for funding under the Federal-Provincial Renewables and Conservation Agreement. The primary objectives of the project include the demonstration of:

1) bog drainage,
2) bog preparation,
3) fuel production,
4) fuel peat utilization for domestic heating,
5) cost of fuel peat production, and
6) cost of domestic heating with peat in comparison to other fuels.

Favourable results may ultimately lay a foundation for the development of a viable energy peat industry and the partial displacement of expensive imported heating oil in northern areas. The project is administered by Saskatchewan Energy and Mines and operated largely through the contracted services of Saskmont Engineering Co. Ltd. and the Department of Northern Saskatchewan. Saskatchewan Minerals Corporation, Carrot River Peat Moss Division has assisted greatly by supplying some of the machinery for bog preparation. The Municipality of Buffalo Narrows as well as several private residents are co-operating in the experimental utilization of peat fuel for heating.

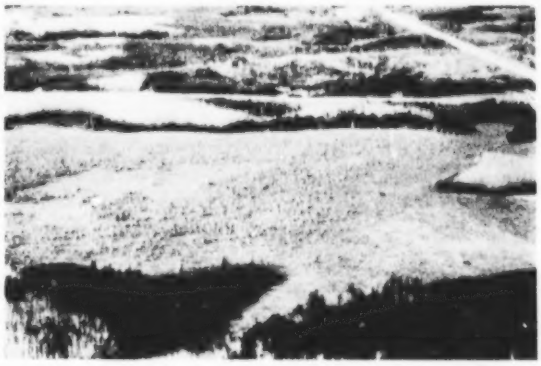

Plate 1 – Oblique airphoto of demonstration bog prior to ditching.

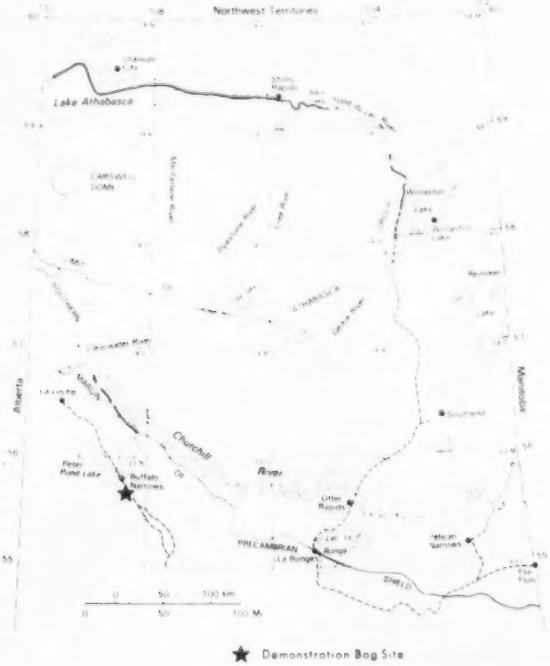

Figure 1 – Location map.

Demonstration Bog

The fuel peat bog chosen for the project is one of many fuel peatlands in the region. It lies on a height of land about 11 km south of Buffalo Narrows on the east side of Highway 155 near its junction with the Dillon road (Fig. 1, Plate 1). Its western edge lies about 200 m east of the highway. An access road commencing about 1 km southeast of the Dillon junction extends from the highway to the project area.

The bog extends over an area of about 60 ha of which 25 ha contain peat deposits at least 1 m thick (Fig. 2). Its location on a local height of land provides excellent drainage in several directions.

Peat in the demonstration bog attains a maximum depth of 2 m and is divided into two well-defined units (Fig. 3). The lower unit, which in places exceeds 1.5 m, consists of fuel quality sedge peat with a von Poste humification (H) factor of 5 or greater. Scattered lenses of less humified peat occur in the unit. Fibrous content increases upward. The upper unit ranges in thickness from 0.3 to 0.5 m. It consists of a mixture of sedge and sphagnum peats, the proportion of sphagnum increasing upward. Peat in the

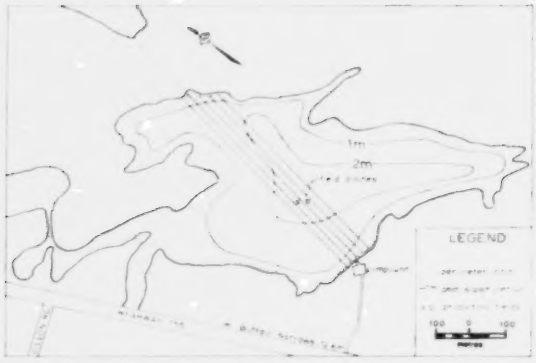

Figure 2—Plan of demonstration bog with peat isopachs and drainage details.

upper unit is relatively fresh, with an H factor generally less than 4.

Bog Preparation

Surveys

Level surveys were conducted along parts of the bog perimeter and through the central area of the bog on a 50 m grid. Probes to determine peat depth were also conducted on the 50 m grid laid out on the bog surface. A peat isopach map and the levelling data assisted in planning of the orientation and location of an effective drainage system (Fig. 2).

A bench-scale sodding and drying test was carried out on peat recovered from a depth of 1 m. Drying for 12 days at room temperature resulted in a moisture reduction from 84 to 35 percent and a good, durable sod capable of withstanding considerable handling.

Drainage

Excavation of drainage ditches took place in late November and early December of 1981 when the bog surface was frozen sufficiently to bear the weight of machinery. Five field ditches were excavated through the central portion of the bog at a spacing of 21 m. The average length of the ditches is about 650 m. Excavation was carried out with a Kopo ditcher powered by a Massey Ferguson 275 tractor modified to negotiate soft organic terrain (Plate 2). The field ditches, cut to a depth of 1 m, were terminated just short of the 1 m isopach to prevent possible damage to the machine by the rocky subsoil of the bog.

Perimeter ditching and connection of the field ditches to the perimeter ditches was carried out by a 20-ton crawler backhoe mounted on 0.76 m wide tracks (Plate 3). About 1000 m of ditching was done on the west side of the bog to effect a northwesterly drainage to an adjacent bog and about 400 m on the north side to take advantage of an established northern outlet. The perimeter ditches as well as the extensions of the field ditches were excavated to a depth of 1.5 to 2 m.

Approximately one week had elapsed between the times of the field ditching and the perimeter ditching. During this time a 10 cm

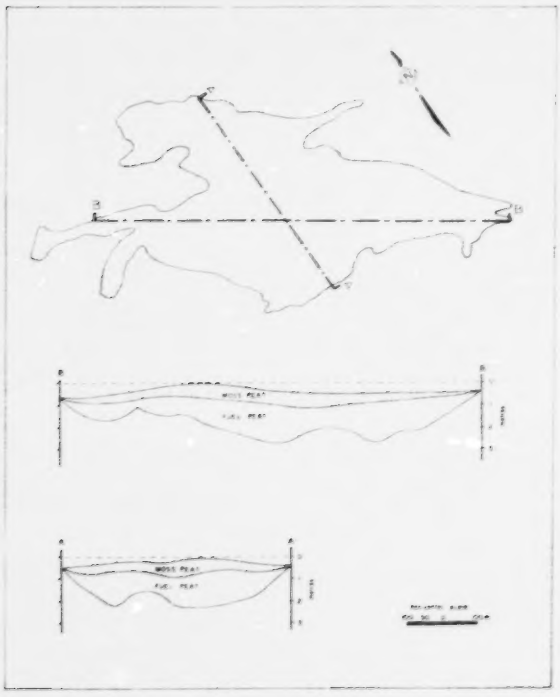

Figure 3—Demonstration bog profiles.

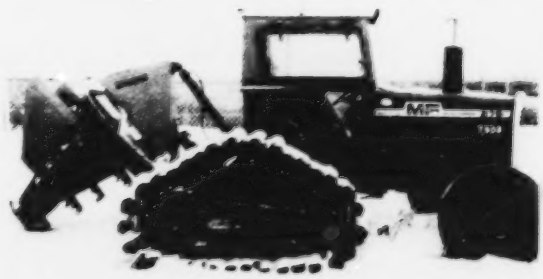

Plate 2—Kopo ditcher and tractor.

Plate 3—Crawler backhoe.

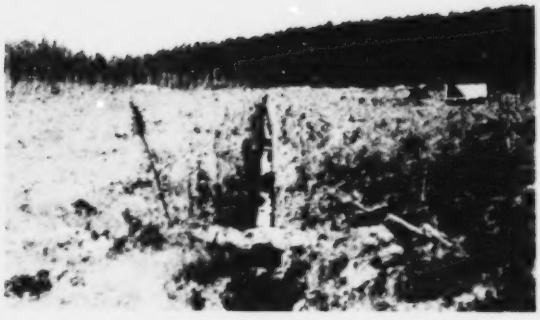

Plate 4—Bridge over field ditch.

layer of ice had developed on the water in the field ditches. When the connection of these ditches to the perimeter ditches had been made the initial flow was very strong. Within 2 days the flow subsided to a steady moderate stream from the five ditches. Flow was much more active from the eastern side of the bog. The thick ice cap and an abundant snow cover on the field ditches provided adequate insulation and allowed drainage to continue throughout the winter.

Subsidence of the centre of the bog, due to drainage, caused a stagnation of the water by mid-summer of 1982. It was therefore necessary to deepen the field ditches to initiate flow once again. Parts of the western perimeter ditch also required deepening due to local wall collapse.

Access

To provide access to the bog and storage for machinery a short gravel road was constructed from Highway 155. The road terminates in a bogside compound measuring about 30 m square.

A bogside road about 600 m long was roughly constructed along the western edge of the bog by levelling the spoil from the perimeter ditch. Besides allowing access onto the bog, this road was used by ditch maintenance machinery and for transportation of bog trees to a disposal site.

Access onto the bog and between the two centre field areas was via two bridges constructed from old power poles and surplus milled poplar logs of the type used in some of the local dwellings (Plate 4).

Tree Pulling

Surface preparation of the two centre fields, each nearly 1 ha in area, commenced with the pulling of all trees with a diameter greater than about 2.5 cm. This was carried out by a Ford 6600 70 HP tractor and two logging chains.

The majority of trees were black spruce with relatively shallow root systems. It was found that uprooting the trees could be accomplished with ease if the logging chains were kept at a low angle with respect to the bog surface. The trees were loaded onto a wagon equipped with a two-sided box to facilitate the operation. Trees were disposed of in a natural clearing adjacent to the bogside road on the west side of the bog. Approximately two weeks were required for tree pulling and clearing by a crew varying from two to four workers.

Brush Cutting, Rotovating and Screw Profiling

Brush and small trees less than 2.5 cm in diameter were cut to ground level by a tractor-mounted Ford 939 brush cutter (Plate 5). Rotovating to a depth of about 20 cm was carried out to loosen the live moss layer and residual tree and brush roots (Plate 6). Rotovating was followed by several weeks of abandonment due to heavy rains. The production fields were then subjected to screw profiling by a Dagleman ground auger (Plate 7) which moved the loose surface material to one side of a field. In a commercial operation the loose material would normally be disposed of and each field would be cambered to promote surface drainage. Rotovating and screw profiling reduce the thickness of the upper peat layer of low humification and assist in increasing the proportion of highly humified peat entering the auger of the sod cutter during the production phase. This is necessary because low-H peat will not form durable sods on its own and will affect the sodding characteristics of good fuel peat. A

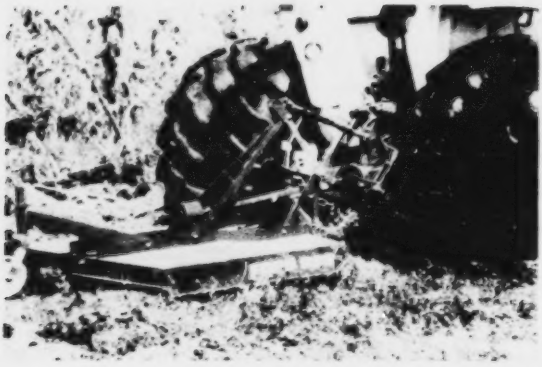

Plate 5 – Brush cutter.

Plate 7 – Screw profiler.

sufficient proportion of high-H peat with its higher colloidal content is required to promote cohesion. Screw profiling also removes most roots which would otherwise tend to plug the sod-cutting machine.

Production Phase

Fuel peat production from the prepared fields (Plate 8) was accomplished with the use of a sod cutter of Finnish origin powered by the power take-off of the Ford 6600 70 HP tractor. The machine (Plate 9) consists of an 80 cm diameter circular steel cutting disc with numerous shallow cups about 4 cm in diameter mounted on its perimeter. The disc, mounted so that it produces a diagonal cut, spins at about 500 rpm counter to the direction of the tractor advance. The ascending cups cut peat from the top 30 cm of the bog and throw it into an opening in a cylinder wall. An auger within the 30 cm diameter cylinder macerates the peat and forces it out through three 10 cm diameter tubes mounted at the lower end of the cylinder. The sods are extruded as sausage-like cylinders varying in length to about 15 cm depending on the condition the peat. The diagonal cuts, about 5 cm and spaced approximately 1 m apart, collap in a short time allowing the next product cycle to commence after the dried sods ha been collected.

If weather conditions are favourable the dry in about two weeks from 80 or 85 perc moisture to a level of about 35 percent. Turning of the sods is required once or t during this period. The project employed manual labor for this operation and for collecting the sods, whereas a commercial operation would be mechanized.

With the proper equipment, favourable weat and a well-prepared surface, an annual production rate of 150 to 200 tonnes per hectare (at 50 percent moisture) would be possible. Unfortunately, poor weather conditions allowed production from only o of the two prepared fields.

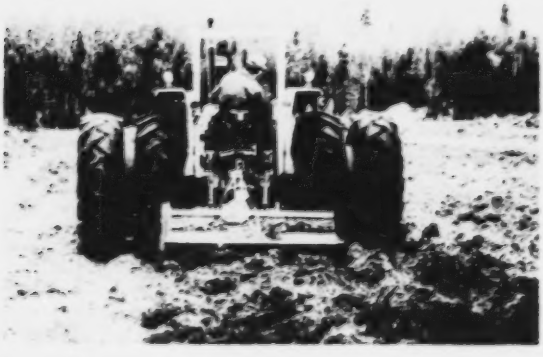

Plate 6 – Rotovator.

Plate 8 – Demonstration bog showing production fields.

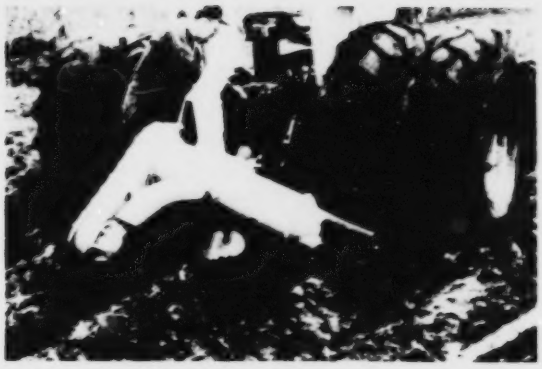

Plate 9—Sod cutter-extruder.

Fuel Peat Trials

Solid fuel peat produced during the fall of 1982 will be used to heat five buildings in Buffalo Narrows during the winter. Three furnaces approved for peat fuel and two combination wood/oil models are installed and ready for use. One of the furnaces, too large and heavy to install in a private home, will heat the Buffalo Narrows Municipal Garage. The three models approved for peat are equipped with water jackets for heating a large insulated water storage tank. The supply water, at a maximum temperature of 120°C, is pumped to a water-to-air heat exchanger mounted in the hot air plenum of the original domestic oil furnace. Heat distribution then takes place in the normal manner of a hot air furnace. This system offers the most practical opportunity for testing the fuel peat as well as providing a back-up system in case of a peat furnace failure.

The system installed in the municipal garage will utilize two 1000 l tanks and a heat exchanger mounted in a simple plenum equipped with a blower of the proper capacity. The two combination wood/oil models will operate as normal hot air furnaces.

Heating trials will be monitored throughout the heating season to provide data on:

1. rate of fuel utilization, including non-peat fuel;
2. fuel moisture, ash and heat value;
3. frequency, time and quantity of furnace loading;
4. frequency and quantity of ash clean-out;
5. outside temperature variation;
6. inside temperature variation;
7. condition of the furnaces, including creosote build-up;
8. flue gas analyses; and
9. carbon content in the ash.

These and other relevant factors including building design and thermal efficiency, family size and lifestyle will be utilized to determine the range of fuel peat requirements for the dwellings. The simpler aspects of monitoring will be handled by each participant in the heating trials. Some parameters, however, will be automatically recorded by special instrumentation. Monitoring data will be collected and interpreted by the Engineering Division of the Saskatchewan Research Council.

Potential For Peatland Development

Approximately 50 percent of the peatland belt between La Ronge - Montreal Lake and Buffalo Narrows - La Loche was examined on a reconnaissance basis. Only a small proportion of this was studied in greater detail. Field data indicate that much of the region may be classified as fuel peatlands. Although total resource figures are not yet available, it can be stated that fuel peat and horticultural peat resources are abundant. Although much of the resources are too remote from potential markets to be considered economically mineable in the foreseeable future, there are nevertheless substantial resources which are relatively accessible.

Of most immediate significance is the prospect of displacing heating oil by an abundant, relatively cheap indigenous domestic fuel supply. The economics of domestic heating by peat fuel on an individual or district basis would depend to a large degree on the scale of development and use. Future prospects for the development of peat resources in the La Ronge area are presented separately (see Troyer, this volume).

Petrology of Potash Ore in the Esterhazy Member of the Middle Devonian Prairie Evaporite in the Esterhazy-Rocanville Area

by L.M. Fuzesy

Study of the Saskatchewan potash ore was continued during 1982. The objective of this work is to understand geological problems which affect or have the potential of affecting the economics of potash mining and safety of the mines. The present report examines the petrology of the Esterhazy Member of the Prairie Formation which is the lowermost of the four potash-bearing members. Particular attention is given to the problems of the origin of carnallite, whose presence is undesirable in the potash mines and avoided as much as possible. Material upon which observations and conclusions are made comprises about 100 samples from the IMC K_1 and PCS Rocanville mines, 38 thin sections and chemical analyses of sylvite, carnallite and halite separated from 45 samples.

The Middle Devonian potash beds were deposited in the inner portion of the Elk Point Basin (Fig. 1). Potash mines are concentrated in three areas of the province. Six shaft mines are situated in the Saskatoon area. Three shaft mines, the K_1 and K_2 of the International Minerals Corporation (IMC) and one Potash Corporation of Saskatchewan (PCS) mine, are in the eastern part of the province, near Esterhazy and Rocanville; and one solution mine is near Belle Plaine.

Figure 1 – Areal distribution of the potash-bearing rocks in the Elk Point Basin.

The potash salts (sylvite and carnallite) occur within halite in the upper part of the Prairie Formation (Fig. 2). Minor anhydrite and carbonate interbeds are present. The average thickness of this southerly dipping formation is around 200 m in the Saskatoon area and 140 m in the Esterhazy-Rocanville and Belle Plaine areas. It lies about 1000 m below surface in the Saskatoon and Esterhazy-Rocanville areas and around 1600 m at Belle Plaine. The Prairie Evaporite conformably overlies the predominantly carbonate rocks of the Winnipegosis Formation, and is unconformably overlain by the Second Red Bed of the Dawson Bay Formation.

The four potash-bearing members of the Prairie Formation (Fig. 2) are, in ascending order, with their common thicknesses in parentheses, the Esterhazy (17 m), White Bear (4 m), Belle Plaine (14 m) and Patience Lake (18 m). The Esterhazy and White Bear Members are present in the southeastern portion of Saskatchewan, the Belle Plaine extends farther west and the Patience Lake extends as far west as the Alberta-Saskatchewan boundary.

The K_1 and K_2 mines of IMC and the Rocanville mine of PCS produce from the Esterhazy Member. The six mines in the Saskatoon area are producing from the Patience Lake Member, and the Belle Plaine Member is solution-mined at Belle Plaine along with the other members. For more information regarding the geology of the Prairie Evaporite the reader is referred to Holter (1969) and Worsley and Fuzesy (1979).

Mineral Composition of the Esterhazy Member

The Esterhazy Member consists primarily of sylvite (KCl), carnallite ($KCl.MgCl_2.6H_2O$) and halite (NaCl). Clay minerals, dolomite and anhydrite normally do not exceed 3 percent of the total rock mass. Iron oxide staining is common throughout.

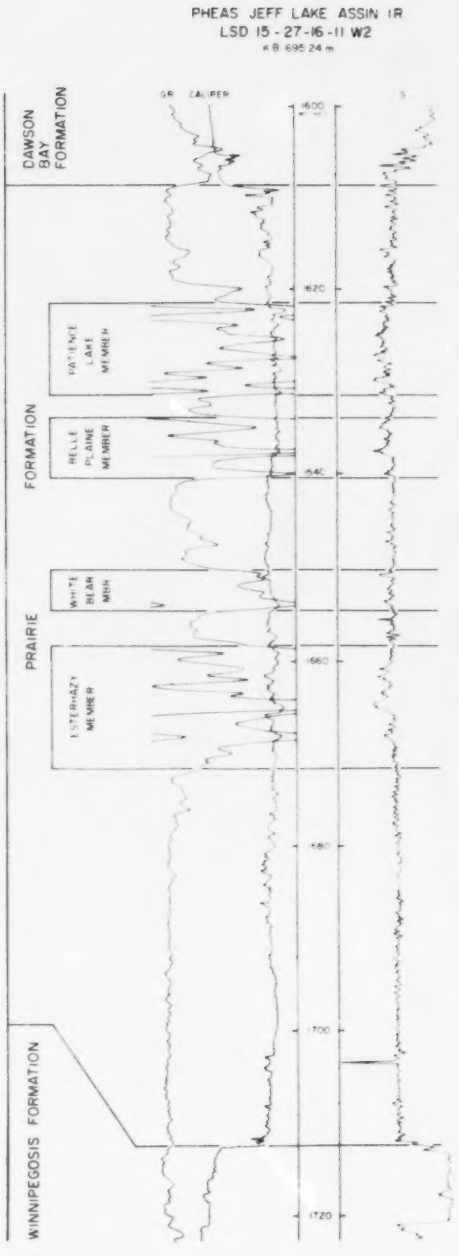

Figure 2—Potash-bearing members of the Prairie Formation.

Halite

Halite crystals are transparent to translucent and mainly colourless or cloudy white. They may also be pink to reddish brown or deep blue. The crystals are normally euhedral to subhedral; anhedral crystals are rare. Common sizes range from about 5 to 15 mm. In thin section the halite is isotropic, commonly with cubic cleavage and very low relief (Plate 1A), and exhibits an interlocking mosaic texture.

Sylvite

The sylvite crystals are colourless, cloudy white, pink or light orange, and less commonly brown, brownish red or light red. Crystals with brown or reddish brown rims occur in places and are transparent to translucent, rarely opaque. They are mainly subhedral to anhedral, generally ranging in size from 5 to 20 mm. Pods of clear sylvite, which occur locally in the IMC and the PCS Rocanville mines, are rounded, normally slightly elongated horizontally and commonly about 60 cm in maximum diameter. In thin section the sylvite is very similar in appearance to halite: both are isotropic and exhibit cubic cleavage and interlocking mosaic texture. However, the appreciably higher relief of sylvite (Plates 1A and B) provides an important distinguishing feature.

Carnallite

Carnallite ranges mainly from light brown to red, but pink, yellow, white or colourless crystals are also common. They are normally translucent, but may be transparent or opaque. Carnallite occurs with halite and sylvite in the potash-bearing strata, and locally as monomineralic veins and pods (Plates 1C and D). The veins vary in width from a few millimetres to approximately 200 mm, and are brownish red in colour. The pods are rounded, slightly flattened and normally up to 1 m in maximum diameter, and are predominantly colourless to white and locally yellow.

The interlocking orthorhombic carnallite crystals are subhedral or anhedral and less commonly euhedral (Plates 1E and F), and have irregular but well-defined boundaries. Crystal size varies widely from less than 1 mm to approximately 80 mm. However, small granular crystals (between 2 and 3 mm) are common. Within carnallite pods the crystals are generally tabular and up to about 80 mm in maximum diameter.

Granules of relict sylvite (rarely halite or dolomite) occur poikilotopically enclosed in carnallite crystals (Plates 2A and B). Carnallite occurs along small cracks in halite and sylvite (Plates 2C and D), and as crystals with halite or sylvite cores (Plate 2E). Carnallite does not have cleavage, but ghost outlines of cubic cleavage are common in the crystals (Plate 2F).

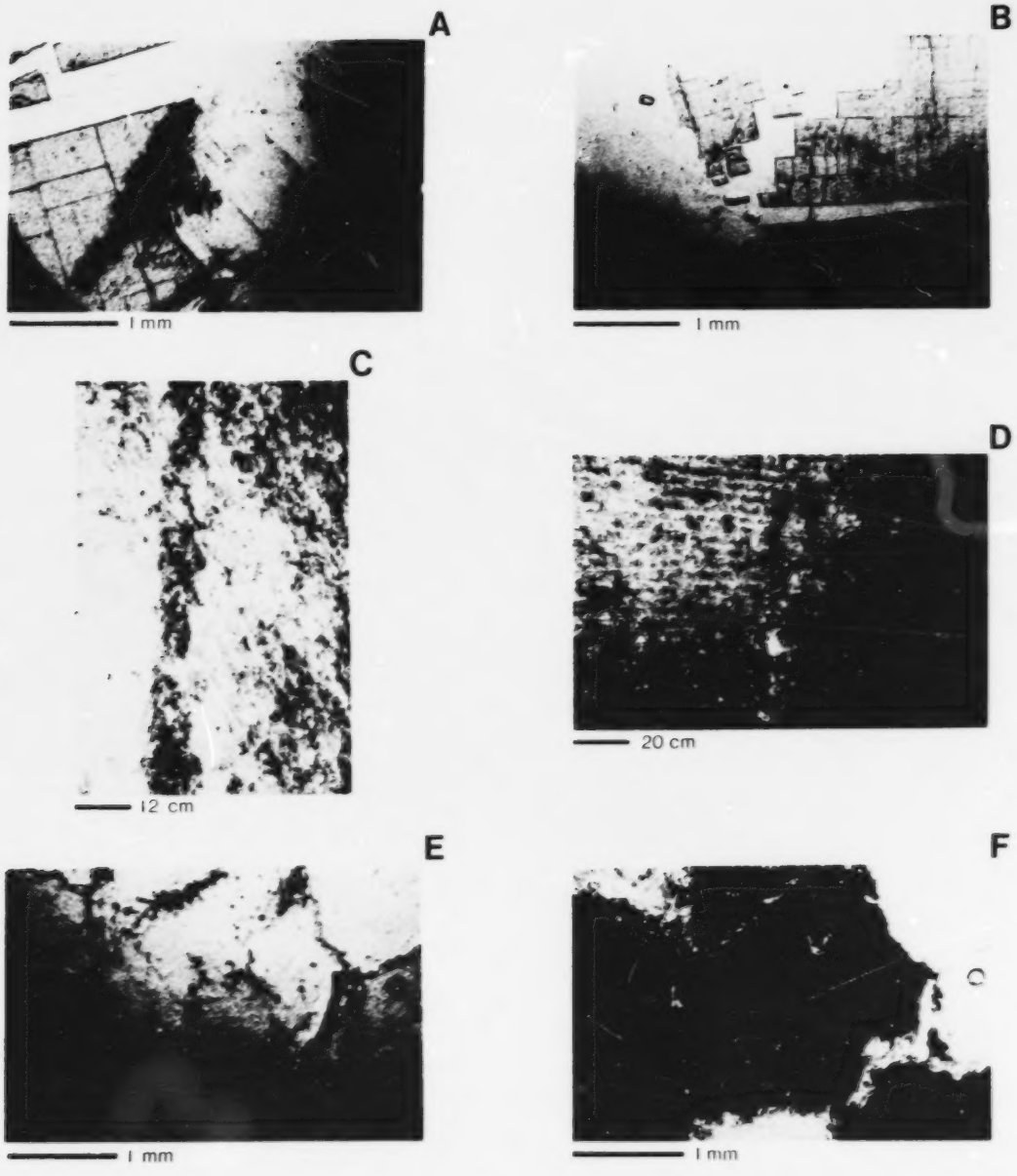

Plate 1—Halite, sylvite and carnallite. A) Sylvite (left side of picture) and halite (middle part of picture) crystals. Note the relatively high relief of the sylvite. Dendritic mass of hematite within sylvite (dark area). Photomicrograph; plane polarized light. B) Sylvite crystals, exhibiting high relief and cubic cleavage. Photomicrograph; plane polarized light. C) Vertical vein of reddish brown carnallite (dark in the illustration) in the rock consists mainly of halite, sylvite and some carnallite. Photographed in the mine. D) Vertical vein (middle of picture) of reddish brown carnallite in the rock consists mainly of halite, sylvite and some carnallite. E) Interlocking carnallite crystals. Photomicrograph; plane polarized light. F) Same as E but with nicols crossed. The fine light specks in dark areas are due to contamination during preparation of thin section.

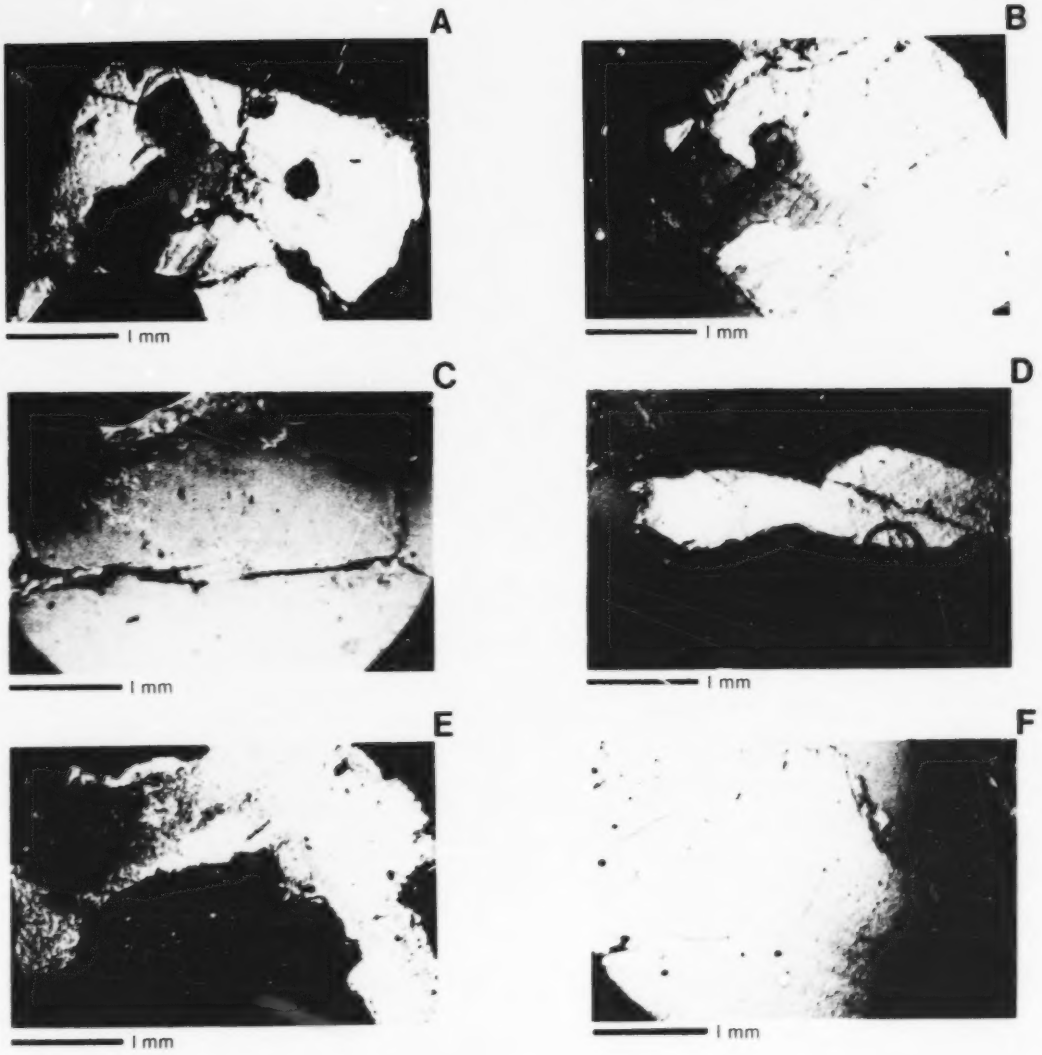

Plate 2—Sylvite and carnallite. A) Carnallite crystals. Note relict sylvite in carnallite (black spherical spot on the right side of picture). Photomicrograph; nicols crossed. B) Sylvite (centre portion of picture) surrounded by carnallite. Photomicrograph; nicols partially crossed. C) Cracks in halite filled with carnallite (upper part of picture). Photomicrograph; nicols partially crossed. D) Carnallite between halite (above) and sylvite (below). Photomicrograph; nicols partially crossed. E) Outer part of sylvite crystal is replaced by carnallite. Photomicrograph; nicols partially crossed. F) Carnallite crystal; note the ghost outlines of cubic cleavage in the crystal. Photomicrograph; nicols partially crossed.

In thin sections, the optical orientation of most of the carnallite crystals is random, but parallel or subparallel alignment of crystals is also present. Most crystals are pleochroic, and exhibit undulatory extinction. Lamellar twinning is common, particularly within carnallite pods (Plate 3A).

Insolubles[1]

Small amounts of clay, anhydrite, dolomite and quartz occur as irregular patches, seams and partings throughout the Esterhazy Member. The concentration of these minerals is quite variable vertically, but it persists uniformly in the horizontal direction within existing mining areas. Specific zones of higher and lower insoluble content are used as guides or for correlation in the mining operation.

The anhydrite patches in halite, sylvite or carnallite are composed almost entirely of elongated lath-shaped crystals (Plate 3B). Laths are up to 350 microns in length but

[1]Not readily soluble in water.

average about 100 microns. They normally lie parallel to subparallel to one another, producing a strongly interlocking gneissoid texture (Bundy, 1956). The crystals are generally bent or exhibit fold-like structures (Plate 3C).

Dolomite crystals are 5 to 10 microns in size and are predominantly anhedral, exhibiting an interlocking mosaic texture. Inclusions of fine dendritic masses and plates of hematite are common in carnallite and sylvite but rare in halite. They are normally concentrated at the margins of the crystals and around or within patches of insolubles (Plates 3D and E).

Carnallite-Rich and Carnallite-Poor Ore Zones

The potash salt deposits in the IMC and PCS Rocanville mines are divided into two distinct groups: one with a high and the other with a low carnallite content. The vertical to near-vertical boundary between the two groups is normally quite sharp. Carnallite-rich bodies occur commonly in the mines under review and generally vary in size from 50 to 200 metres across. Within the carnallite-rich zones sylvite occurs as a subordinate mineral, and locally the reddish-brown carnallite crystals are concentrated into vertical, irregular, commonly discontinuous stripes and bands (Plate 3F and G). In the carnallite-poor areas the carnallite content of the potash ore is normally less than about 8 percent of the total rock mass.

Maintenance of the mine in the carnallite-rich zone is much more difficult than it is in the carnallite-poor area due to roof fall and floor heave. The potassium content of the carnallite is 14 percent (equivalent of 17 percent K_2O) as opposed to sylvite, the desired mineral, which contains 52 percent potassium (equivalent of 63 percent K_2O).

Bromine Geochemistry

The amount of bromine in halite, sylvite and carnallite is significant in the interpretation of the origin of these minerals. Bromine occurs as a solid solution substitution for chlorine. The bromine content of a chloride mineral is dependent on the amount of bromine in the crystallizing solution and also on its own distribution coefficient (Chirkov, 1946), defined as:

$$\frac{\text{bromine content of the crystal (wt \%)}}{\text{bromine content of the liquid phase from which the salt crystallized (wt \%)}}$$

The distribution coefficient for halite at the beginning of its precipitation is 0.14 and it is 0.073 at the beginning of carnallite precipitation. The distribution coefficients for sylvite and carnallite are 0.73 and 0.52 respectively (Braitsch and Herrmann, 1963). These figures are less than unity; consequently, the bromine content of the residual seawater progressively increases after the precipitation of the first halite crystal. The ratio of the bromine content in halite, sylvite and carnallite is 1:10:7 when they precipitate simultaneously (Braitsch, 1962). At the beginning of sylvite precipitation the bromine content of the halite should be 270 ppm (Valyashko, 1956, p. 578). Halite samples analyzed in this study contain much lower levels of bromine (Table 1), suggesting that recrystallization has taken place (cf. Wardlaw, 1964; McIntosh and Wardlaw, 1968). Values for bromine in sylvite and carnallite are also low in comparison with bromine in these potash minerals precipitated from present-day seawater (Valyashko, 1956). However, it is significant that the average values of bromine in sylvite and carnallite in carnallite-rich zones are similar. It is suggested that one mineral replaced the other and incorporated its bromine content.

Table 1. Average bromine content in halite, sylvite and carnallite in the Esterhazy and Rocanville mines

	Halite	Sylvite	Carnallite
Carnallite-poor zones	108 ppm	1320 ppm	
Carnallite-zones	131 ppm	1290 ppm	1300 ppm
Pods			1500 ppm
Salt horses	87 ppm		

Discussion

This study indicates that most, if not all, of the carnallite occurring in the three mines within the Esterhazy Member is younger than either the sylvite or the halite. Evidence for this includes:

1. The occurrence of relict sylvite, halite and dolomite in carnallite crystals.

2. The marginal replacement of sylvite and rarely halite by carnallite (centripetal

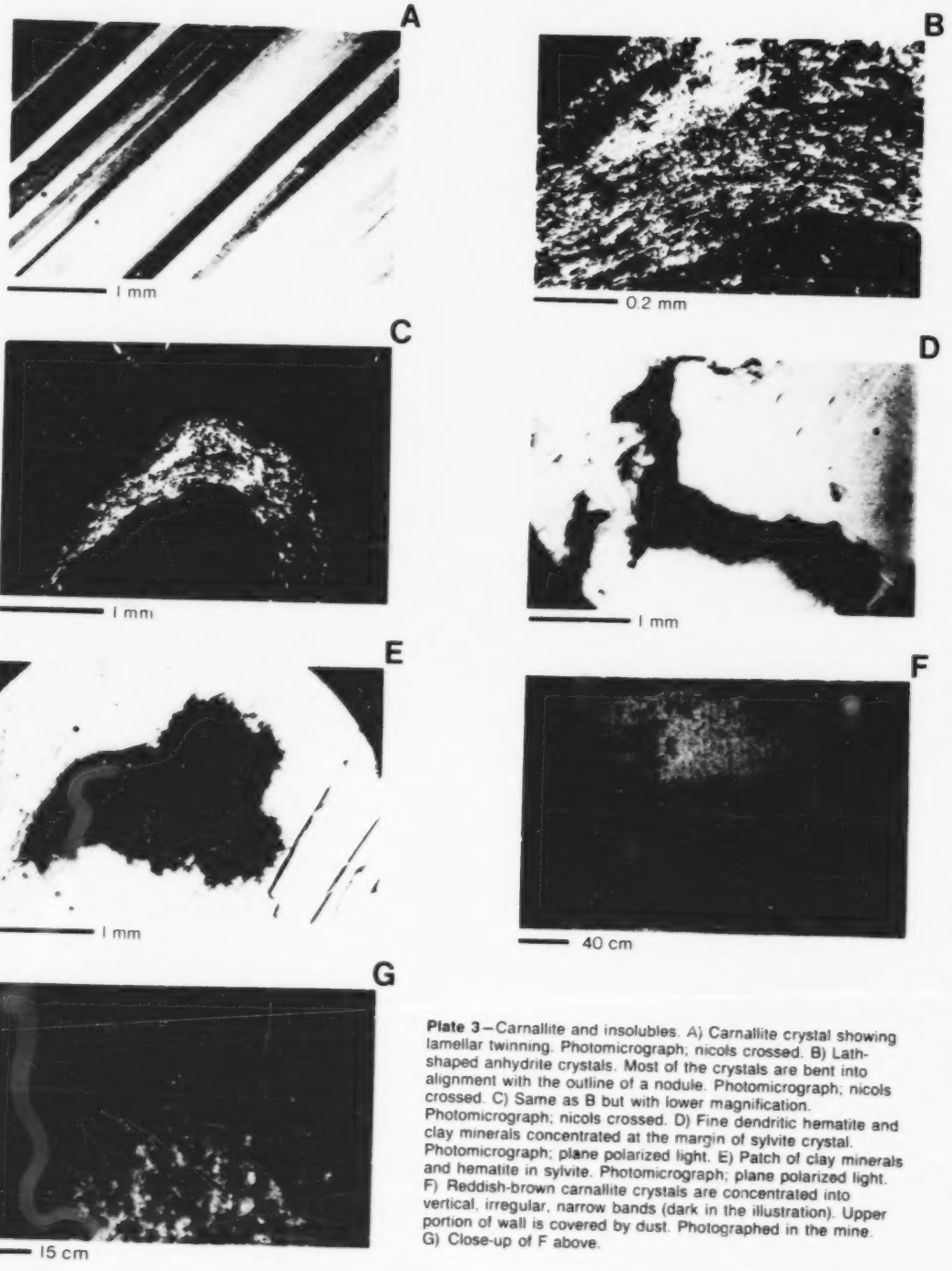

Plate 3—Carnallite and insolubles. A) Carnallite crystal showing lamellar twinning. Photomicrograph; nicols crossed. B) Lath-shaped anhydrite crystals. Most of the crystals are bent into alignment with the outline of a nodule. Photomicrograph; nicols crossed. C) Same as B but with lower magnification. Photomicrograph; nicols crossed. D) Fine dendritic hematite and clay minerals concentrated at the margin of sylvite crystal. Photomicrograph; plane polarized light. E) Patch of clay minerals and hematite in sylvite. Photomicrograph; plane polarized light. F) Reddish-brown carnallite crystals are concentrated into vertical, irregular, narrow bands (dark in the illustration). Upper portion of wall is covered by dust. Photographed in the mine. G) Close-up of F above.

replacement, observed in thin sections and hand specimens).

3. Traces of cubic cleavage in carnallite crystals suggest that they were formed by the replacement of sylvite or halite.

4. The occurrence of vertical, highly carnallitic stripes and bands in carnallite-rich zones.

These observations suggest that the carnallite is the product of diagenetic changes brought about by vertically moving fluids. Carnallitized rocks in the mines appear to be associated with disturbed fractured zones, now partially obscured because of the high plasticity of the halite and potash minerals.

The structurally disturbed zones are believed to be coincident with Winnipegosis reefal mounds below the Prairie Evaporite (Gendzwill, 1978; G.S. McVittie, Cominco Ltd., Vanscoy, Sask., pers. comm.). This relationship appears to be the result of a partial dissolution of the salt by water flow through Winnipegosis mounds and consequent collapse and fracturing. Most of these fractures probably affect the overlying Dawson Bay mudstones and carbonates. The presence of magnesium-rich waters is essential for the process of carnallitization. The most likely source of magnesium is the Winnipegosis and/or Dawson Bay carbonates. The common occurrence of eogenetic and mesogenetic dolomites in both the Winnipegosis Formation (Fuzesy, 1975) and the Dawson Bay Formation (Dunn, 1982) is convincing testimony of the presence of magnesium-rich fluids within these carbonates at certain geological times. The high magnesium content of these fluids probably originated from supratidal zones (Fuzesy, 1975). Another possible source of magnesium is clay minerals occurring within the Prairie Formation and/or in the overlying Red Beds of the Dawson Bay Formation. Increased magnesium concentration in fluids migrating through magnesium-bearing clay-rich layers can be explained by magnesium-calcium ion exchange (Chave, 1960). Magnesium could also have been derived from primary precipitates. Magnesium chlorides (e.g. carnallite and bischofite ($MgCl_2.6H_2O$)) may have been among the primary minerals of the Prairie Evaporite. Dissolution of these highly soluble minerals could have provided magnesium for late carnallitization.

Small patches of dolomite and anhydrite in these potash-bearing rocks may be early eogenetic in origin (cf. Fuzesy 1970, 1973 and 1975). The small size (5 to 10 microns) of the anhedral dolomite crystals suggests early eogenetic origin. Dolomite was probably formed under sabkha-like conditions by penecontemporaneous replacement of calcium carbonate sediments. The elongate lath-shaped crystals, the gneissoid texture and the fold-like structure of the anhydrite bear a striking similarity to Recent early diagenetic sabkha-type anhydrite (e.g. Kinsman, 1966; Shearman, 1966; Shearman and Fuller, 1969). These dolomite and anhydrite patches appear to be small, irregularly eroded, transported fragments of pre-existing dolomite and nodular anhydrite.

Conclusions

It is likely that the three main minerals of the Esterhazy Member (halite, sylvite and carnallite) are secondary in origin. Furthermore, both the halite and sylvite are older than most of the carnallite. The locally occurring carnallite-rich zones are the result of the process of mesogenetic carnallitization. The magnesium-rich fluids percolating through these rocks altered most of the sylvite and some of the halite.

Acknowledgements

The author wishes to express his sincere thanks to Mr. S. Duncan and Mr. M.A. Molavi for providing information concerning the geology of the IMC Esterhazy and PCS Rocanville mines, respectively. Their excellent guidance in the mines was also much appreciated.

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ABSTRACTS OF SASKATCHEWAN ENERGY AND MINES REPORTS

The following are abstracts of reports by the Saskatchewan Geological Survey published during the past year or scheduled to be released before December 31, 1982:

Colborne, G.L. (1982): Geology of the Lowe Lake (east) area; Saskatchewan Mineral Resources, Open File Report OF 82-1(map only).

Dunn, C.E. (1982): Geology of the Middle Devonian Dawson Bay Formation in the Saskatoon potash mining district, Saskatchewan; Saskatchewan Energy and Mines, Report 194, 117p.

Carbonates and evaporites of the Dawson Bay Formation overlie the salt beds of the Prairie Evaporite in the 24,000-km^2 area of central Saskatchewan considered in this study. The geology of the formation is relevant to the operations of six potash mines, in that the ore is extracted from the Patience Lake Member, only a few metres beneath the Dawson Bay.

The formation underlies the Souris River Formation and is Givetian in age. The current subdivision of the Dawson Bay Formation into six units is reduced here to four formally defined members (in ascending order):

1. Second Red Bed Member, composed of dolomitic mudstone;
2. Burr Member (new name), composed of limestone with some dolomite, and characterized by abundant discontinuity surfaces ("hardgrounds");
3. Neely Member (new name), composed of stromatoporoidal limestone capped with dolomite and anhydrite;
4. Hubbard Member, composed of halite.

The sediments were deposited in shallow tropical seas relatively free of clastic material. Hardgrounds give witness to at least 25 occasions when sedimentation temporarily ceased. Evaporation of the sea left the Hubbard halite in the eastern part of the study area. Later, porosity of the sediments was plugged with halite over thousands of square kilometres.

Cores of the Dawson Bay show abundant near-vertical fractures. Structure contours indicate regions of major subsidence due to solutioning of the Prairie Evaporite with associated severe brecciation of the Dawson Bay strata. Moreover, regions of relatively thin salt above the potash-rich Patience Lake Member are considered evidence for partial solutioning.

The potash mines are situated beneath Dawson Bay strata which are dry. Water-bearing zones in the Dawson Bay trend north-easterly, and are coincident with seismic lows. Sparse water pressure data permit a tentative evaluation of the potentiometric surface: decline is toward the northeast, and elevations are coincident with those in the Mannville indicating connection between the formations. A possible potentiometric cell exists southwest of Saskatoon.

Rock mechanics data show that Dawson Bay rocks are generally very strong, and are of the moderately high elasticity expected for carbonates. Compressive strengths are relatively low in the presence of abundant fauna, bituminous laminae, and hardgrounds.

Fuzesy, Anne (1982): Index to assessment work in the Reindeer Mining District of Saskatchewan; Saskatchewan Mineral Resources, Miscellaneous Report 82-10, 172p.

This index is designed to inform the users, particularly those interested in Precambrian exploration, of the types of data available to them in the files of the Geology and Mines Division of Saskatchewan Energy and Mines.

The files listed are those submitted to the department by industry engaged in geological, geophysical and geochemical exploration in Northern Saskatchewan.

Entries in the index are grouped according to the numeric and alphabetic system of the National Topographic System (NTS) grid. The Reindeer Mining District is adjacent to the Manitoba border between latitudes 54° and 60° north and extends westward as far as longitude 104°.

It includes all or parts of 63K, L, M, N and 64D, E, L, M.

Each entry briefly describes the type of survey undertaken, the documents filed and gives assay results for non-confidential files. Drillhole core now stored at Saskatchewan Energy and Mines core laboratories at La Ronge or Regina is identified. A property index provides a cross-reference listing of claim names, claim block numbers, mineral prospecting permits, permits, mineral leases, concessions, mines and properties not included in any of these groups.

This index supersedes the 1979 Index to Assessment Work in the Reindeer Mining District (Miscellaneous Report 79-3).

Fuzesy, Anne (1982): Potash in Saskatchewan; Saskatchewan Energy and Mines, Report 181, 44p.

Soluble potassium salts present in a crystalline form in some bedded salt deposits supply most of the world's demand for potassium for agricultural and industrial use. During the search for oil in southern Saskatchewan in the early 1940s, sylvite (KCl) and carnallite ($KCl.MgCl_2.6H_2O$) were noted in salt core but uncertainties as to markets, depth of the deposits and the feasibility of solution mining delayed potash exploration for ten years. Eventually, what are thought to be the largest deposits of high-grade potash in the world were outlined.

The potash deposits in southern Saskatchewan occur within the uppermost 60 metres of the Middle Devonian Prairie Evaporite at depths in excess of 900 metres. Their northern limit roughly parallels the Yellowhead highway. They extend a few kilometres into Manitoba, and southwards, at increasing depth, into North Dakota and northeastern Montana. Individual potash-rich beds are extensive and consistent in grade and thickness. Local thickening occurs where carnallite, not sylvite, is the dominant potash mineral. Other anomalous sequences in which beds normally potash bearing are halitic or missing are related to non-deposition, erosion, or dissolution. Four groups of potash-bearing halite beds have been distinguished: the Esterhazy, White Bear, Belle Plaine, and Patience Lake Members.

The preferred ore is a clean mixture of sylvite and halite (sylvinite). Carnallite and insolubles are avoided wherever possible because of their detrimental effects on mine stability, ore grades and refining processes. The ore is extracted by shaft mining or dissolved and brought to the surface as brine. Flotation or crystallization processes separate the potash from the salt and the refined product, potassium chloride, is supplied as a fertilizer ingredient and also for chemical and other industrial uses. Some salt is processed for food salt, some is used directly as road salt, but the bulk of the salt tailings is impounded at the surface as waste. Excess brine may be injected into underground rock formations.

Problems with shaft sinking and with solution mining experiments beset the pioneering potash companies and it was 1962 before continuous production was under way. In 1964 the world's first potash solution mine came on stream. The conventional mines are between 950 and 1075 metres deep. There are three mines near the Manitoba border in the vicinity of Esterhazy, six east and west of Saskatoon and a deeper solution mine at Belle Plaine, between Regina and Moose Jaw.

The ten potash mines in Saskatchewan presently account for more than seven million tonnes of potash* or about 25 per cent of the annual world production. The biggest customer for Saskatchewan's potash is the United States (about 65 per cent of sales), followed by Brazil, Japan, Canada (chiefly Ontario and Quebec), India and recently, the People's Republic of China. Altogether, shipments to 25 countries were recorded in 1980. Sales were worth just over $1 billion; provincial revenues from potash amounted to $280 million, and approximately 4,050 people were directly employed in the industry.

At present, the Saskatchewan mines have a total annual design capacity of nearly thirteen million tonnes potassium chloride product (equivalent to about eight million tonnes K_2O). Most facilities are being expanded to some degree; the capacity of the Lanigan mine should be tripled by 1983 and a new mine is being planned for the Bredenbury area.

In other parts of Canada, two exploratory potash shafts are being sunk in New Brunswick with the intent of developing two mines; development of a potash mine is being planned in Manitoba following favourable exploration results; and potash exploration programs have recently been reported in Cape Breton, Newfoundland and at prospects elsewhere in New Brunswick and Manitoba.

*metric tons K_2O equivalent

Gilboy, C.F. (1982): Classification of clastic metasediments; Saskatchewan Mineral Resources, Open File Report OF 82-3, 33p.

This report comprises a collection of tables and diagrams, and makes recommendations with respect to the classification of clastic metasedimentary rocks. Produced by Dr. Gilboy for in-house usage in connection with the Sub-Athabasca Basement Geology Project, the report is being open-filed because of its relevance to the Precambrian in general. The report is reproduced in unedited form.

Harper, C.T. (in press): Iron ores of northern Saskatchewan; Saskatchewan Energy and Mines, Report 220.

An integrated geological, geophysical and geochemical assessment of various types of iron occurrences was carried out in the Precambrian Shield area of northern Saskatchewan to determine whether there are any economically viable deposits. For the purposes of this study, an economically viable deposit had to be capable of supplying at least 100 million tonnes of ore grading at least 30 percent Fe, mineable by open pit methods, amenable to relatively simple concentrating procedures and readily accessible from existing and proposed transportation routes.

The iron occurrences investigated include metataconite (metamorphosed and extensively recrystallized) oxide facies sedimentary iron formation (Triana, VH, Ithingo Lake, Dot Lake, Fish Hook Bay and Spence Lake), sulphide facies iron formation and genetically related barren massive iron sulphide deposits (Nistoassini Lakes, Kirk Lake, Forbes Lake and Gossan Lake), deposits of plutonic association (Bassett Lake, Clearwater River and Olsen showing), significant aeromagnetic anomalies of uncertain cause (Kelic Lake and Popplewell Island), and residual deposits (bog iron ore and iron-cemented tills) which are closely associated with the iron sulphide deposits.

Superior-type banded quartz-magnetite/hematite metataconite deposits are most common in the Cree Lake Zone and less important in the Western Craton, with small Algoma-type oxide facies iron formations being present in the La Ronge Domain. Volcanogenic iron sulphide deposits are most common in the metavolcanic terrain of the La Ronge Domain and are smaller and less important in the Rottenstone, Glennie Lake and Flin Flon Domains. Some impressive but small residual bog iron occurrences accompany the sulphide deposits. Iron occurrences of plutonic association are not abundant in any region, but the best, Bassett Lake, is in a layered ultramafic intrusion in the La Ronge Domain.

Despite the relative abundance of metallic iron in northern Saskatchewan, none of the deposits appears to be economically viable at this time.

Rees, C.J. (1982): Metamorphism in the Canadian Shield of northern Saskatchewan; Saskatchewan Mineral Resources, Open File Report OF 82-2, 136p.

This thesis presents the first attempted regional synthesis of metamorphism in the Canadian Shield in Saskatchewan, and examines its significance in relation to formerly recognized lithostructural elements, and to the thermotectonic evolution of the region in general. Data concerning metamorphic minerals, the nature of magmatism and migmatization, and deformation/recrystallization age relations have been extracted from existing geological work, and collated to produce a 'first appearance isograd' map and a metamorphic facies map.

The results reveal that major polymetamorphism (polycyclic) is restricted to the west of the Saskatchewan Shield where an Archean craton with high grade Kenoran parageneses is mildly retrogressed by a low grade Hudsonian event, much stronger in localized shear zones of intense Hudsonian reworking. Over the remainder of the study area an essentially monometamorphic (Hudsonian) pattern is apparent, which is spatially related to the distribution of Archean basement and to the nature of Aphebian supracrustal development, criteria previously used to define 'lithostructural domains'. Basically, domains comprising Archean-Aphebian miogeosynclinal successions sustained high grade metamorphism and infrastructural remobilization, while Aphebian eugeosynclinal successions are characterized by more spatially variable low to high grade metamorphism and intensive magmatic intrusion. Within areas of lithostructural homogeneity, metamorphic grade is generally uniform, but junctions between different domains usually coincide with steep metamorphic gradients, particularly where related to major synmetamorphic shear zones and ductile faults.

Age relations indicate that this thermal structure was initiated early and rapidly in the Hudsonian cycle and remained essentially immobile and at peak grade throughout major tectonism. The steep metamorphic gradients are mostly primary prograde features (except in the reworked Archean craton); they are neither the results of 'fronts of retrogression' induced by later events, nor apparently the effects of post-metamorphic differential uplift and erosion.

Mineral isograd sequences are similar throughout the Shield and indicate that the erosion surface is essentially isobaric, and lies within a P-T field at approximately 4 $\pm$ 1 kb between 450° and 800°C. Geothermal gradients are estimated and do not suggest abnormal heat flow.

The correlation between metamorphic grade and well-defined pre-Hudsonian crustal elements is argued to be the result of primary lateral contrasts in the mode of heat transfer and hence geothermal gradients, induced by corresponding variations in physical properties of the crust. The major metamorphic/tectonic discontinuities may represent ancient crustal features, intimately related to Aphebian supracrustal development, and later to the distribution and diffusion of the Hudsonian orogenic heat flux.

Simpson, F. (1981): Lithologic descriptions of selected cored sections from the Colorado and Montana Groups (Middle Albian to Campanian) of Saskatchewan; Saskatchewan Mineral Resources, Report 233, 72p.

The research project, designated *Low - Permeability Gas Reservoirs in Marine, Cretaceous Sandstones of Saskatchewan*, is the basis for an agreement between the Saskatchewan Geological Survey and the Department of Geology, University of Windsor, Ontario. In accordance with this agreement, a detailed, stratigraphic-sedimentologic study is being made of sandstone and siltstone bodies of marine origin, referable to the Colorado and Montana Groups of Cretaceous age. These sandstones and siltstones are characterized by varying degrees of shaliness and by gradational relationships with the enclosing mudstones. It is not surprising, therefore, that in addition these lithologies typically display low permeability.

The present account brings together descriptions of some 120 cored sections from strata of the Colorado and Montana Groups. The core descriptions herein provide the basis for relating lithologic features to fluid-flow characteristics, which is a secondary objective of the project as a whole, and form the first phase in a continuation of work previously carried out by the author on the Lower Colorado strata of Saskatchewan.

Simpson, F. (1982): Sedimentology, paleoecology and economic geology of Lower Colorado (Cretaceous) strata of west-central Saskatchewan; Saskatchewan Energy and Mines, Report 150, 183p.

The Colorado Group (middle Albian to Santonian) of the Canadian Great Plains was deposited in an epeiric sea, which occupied an asymmetrically subsiding structural basin, located to the east of the rising Cordilleran mountain belt. In Saskatchewan, Colorado lithologies reflect two largely transgressive phases of dominant mud deposition and an intervening regressive phase, represented by a northeastward-thinning wedge of conglomerates and sandstones, which grade into fine-grained deposits. The Colorado succession is divided into upper and lower subgroups at the disconformity marking the base of the lower of two widespread calcareous marker units, the Second White-Speckled Shale (Turonian). Fluctuation in subsidence relative to sedimentation produced shifting spatial relationships between two major shelf areas, which were sites of sand deposition (notably in Lower Colorado time) and a central basin where muds were laid down: the rapidly subsiding western shelf received large volumes of siliciclastics from the rising Cordilleran uplifts, whereas the comparatively quiescent eastern shelf was supplied with relatively minor quantities of sediment from the Precambrian Shield. The chief agents of sediment dispersal were storm-surge-augmented tidal currents that produced large-scale sand ridges and tidal-channel deposits.

The Joli Fou Formation reflects the early transgression and consists of sporadic, thin reworked relict deposits succeeded by fine-grained, shaly, glauconitic sandstones of an estuarine delta (Spinney Hill Sandstone), which are overlain by and grade southwestward into non-calcareous mudstones. The dominant biofacies is vital-heterostrate, with ostracodes, agglutinating Foraminifera, bryozoans, pelecypods, discinoscid and lingulid brachiopods and ophiuroids, in addition to death-assemblages of radiolarians and diatoms in phosphorite nodules and current-formed accumulations of fish-skeletal debris.

The Viking Formation consists of conglomerates and shaly sandstones in dominantly coarsening-upward sequences, deposited mostly during the regression on the western shelf as nearshore sand bodies and tidal sand ridges upon a thin layer of reworked, relict gravels. The Viking sandstones incorporate lethal-heterostrate biofacies, comprising exotic debris and reworked Joli Fou fossils, and vital-heterostrate biofacies. The latter are characterized by trace-fossil assemblages of associated, second-order biofacies, which include deep, vertical, tubular burrows (nearshore), deep *spreite* burrows (proximal shelf), and shallow *spreite* burrows, associated with horizontal, branched forms (distal shelf). Low-permeability, bioturbated, shaly sandstones constitute the main reservoir lithology of the Kindersley production district; biogenic destruction of primary layering has largely eliminated the shale breaks which form the numerous reservoir heterogeneities commonly associated with sandstones and conglomerates of higher permeability. The Flotten Lake Sand displays southwestward diminution of grain size and thinning along the erosional edge of the Colorado sequence. The transgressive Big River Formation is largely made up of non-calcareous basin and distal-shelf mudstones and incorporates the widespread, northeastward-thinning Fish-Scale-Marker, which contains abundant sand-grade fish-skeletal debris as graded beds. Below the marker, the Big River mudstones pass northeastward into the fine-grained, kaolinitic, shaly St. Walburg Sandstone. Above, the Big River mudstones contain abundant megaspores, frequently tightly packed on bedding planes. The boundary between Early and Late Cretaceous strata is at or near the base of the marker unit.

The Sweetgrass arch appears to have influenced Lower Colorado sedimentation across the western shore-to-basin transition, principally by limiting the eastward dispersal of regressive sandstones. The eastern shelf coincided with a structural platform, approximately delineated in the south by the modern North Saskatchewan River.

The Viking oil and gas reservoirs occupy the updip pinchouts of nearshore and proximal-shelf sandstones on the Sweetgrass arch, where drape folds in the Colorado succession mimic cuesta and valley forms at the sub-Cretaceous unconformity, notably along the northern limits of subcropping Jurassic and Mississippian strata respectively. The capping lithologies of the reservoirs are frequently thin layers of strongly indurated sandstone, cemented by calcite, siderite and subordinate pyrite. These are located at the tops of coarsening-upward sequences, usually a few metres below the contact with the shale. These cement-rich layers are the permeability barriers, which, to a large extent are responsible for the low reservoir pressures commonly associated with Viking production. Hydrocarbon prospects lie in the nearshore and proximal-shelf Viking facies, occupying little explored domal features immediately south of the Dodsland-Hoosier production district. Distal-shelf Viking facies of the Unity-Vera area remain prospective for relatively small accumulations of natural gas. The St. Walburg Sandstone and Flotten Lake Sand are also prospective for gas in the western part of the eastern shelf, where local dip reversals have resulted from collapse of strata following solution and removal of Middle Devonian evaporites. The best prospects in the Spinney Hill Sandstone are also associated with solution-generated collapse structures in the distal-shelf facies of the unit.

ACKNOWLEDGMENTS

Senior assistants who assisted project leaders in the field are named on the accompanying maps. Full acknowledgment for assistance in the field is expected to be made in the final reports, where applicable.

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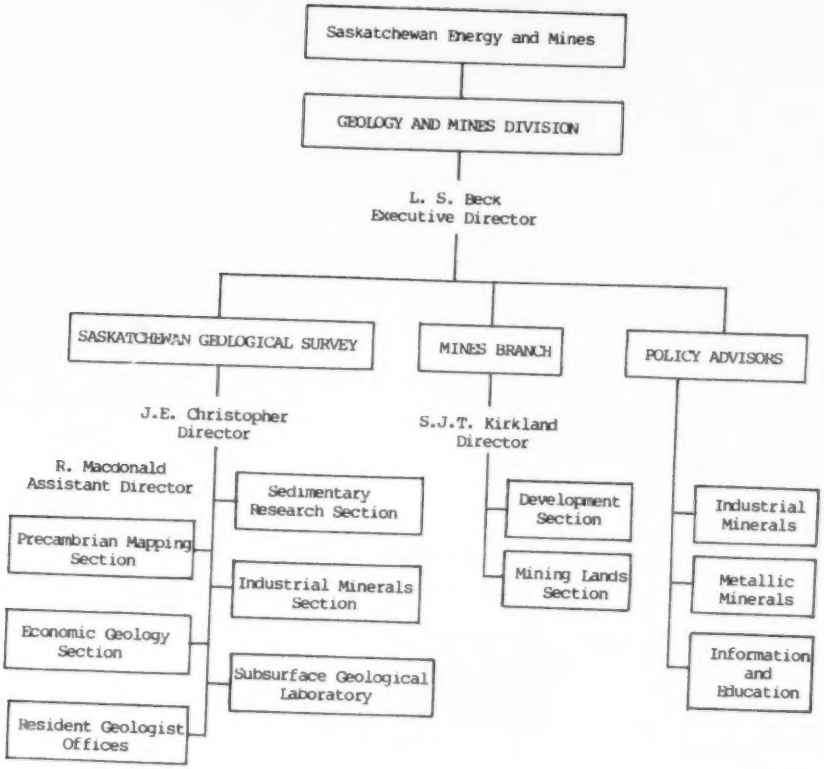
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(T) indicates temporary position
* seconded until December 1982 to Mines Branch

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Compilation Bedrock Geology: Wollaston Lake Area (NTS 64L)

Preliminary Geological Map

by **M. W. THOMAS**

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SYMBOLS

Geological boundary; approximate, inferred

Structural lineament, possible fault, as interpreted from geological, geophysical and/or airphoto evidence

Mineral prospect or deposit

Weathered, saprolitic bedrock

$\triangle_2$ Radiometric age date location (approximate):

1 1670 Ma K-Ar biotite age; Lowden, J.A. (1961), Geol. Surv. Can., Pap. 61-17, p. 40

2 2600 Ma Rb-Sr whole rock age; Chandler, F.W. (1977), Geol. Surv. Can., Bull. 277, p. 20

× Bedrock exposure

Area of abundant bedrock exposure

LEGEND

NEOHELIKIAN/HADRYNIAN

db — Diabase dyke: inferred from linear aeromagnetic anomalies; smaller dykes are fine grained, massive, ophitic textured, + clinopyroxene + plagioclase + potassium feldspar + quartz; intrudes high grade crystalline rocks and Athabasca Group sandstone

PALEOHELIKIAN

ATHABASCA GROUP

S — Manitou Falls Formation: unmetamorphosed, fluviatile quartz sandstone with 2 to 20 percent interstitial clay and interbedded, clast-supported conglomerates near base; underlying basement is deeply weathered; locally faulted against basement

SS : quartz sandstone

SC : interbedded sandstone and conglomerate

MUDJATIK AND WOLLASTON DOMAINS

LATE APHEBIAN (HUDSONIAN)

Wb — Basic to ultramafic rocks: amphibolite, hornblende metagabbro, metadiorite and metapyroxenite; occuring as small bodies in the Wollaston Domain;
ages and origins uncertain, possibly intrusive

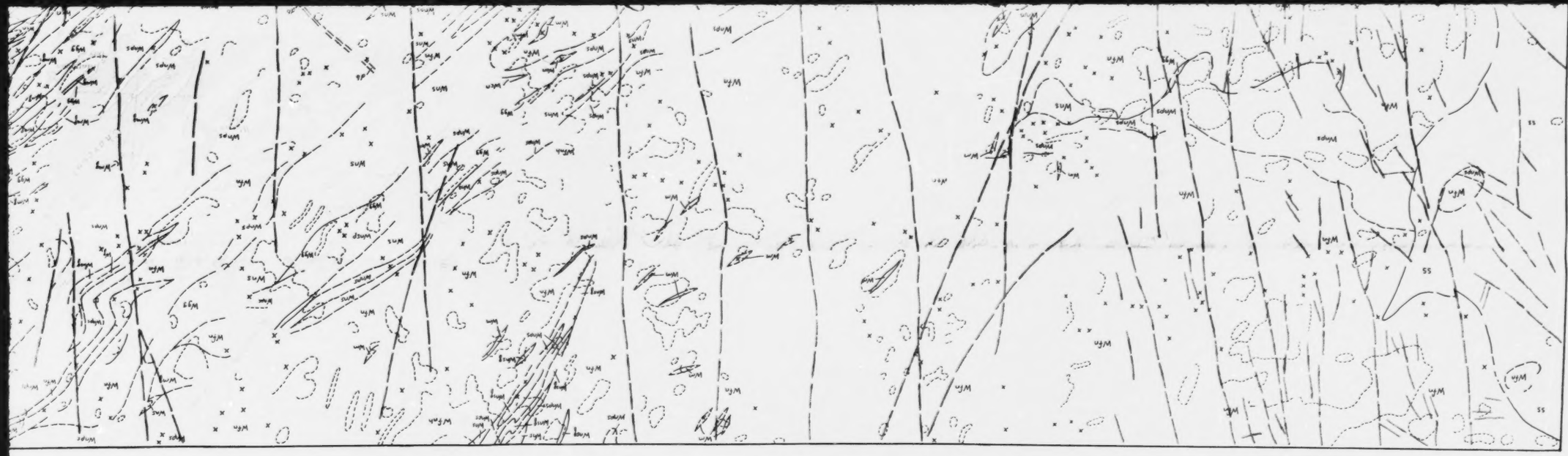
Wgg — Tonalite, granodiorite and monzogranite: medium grained to pegmatitic, locally megacrystic, + biotite + hornblende + garnet, local pelitic and/or amphibolitic xenoliths;
in part derived by anatexis of Wollaston Group supracrustal rocks, in part plutonic

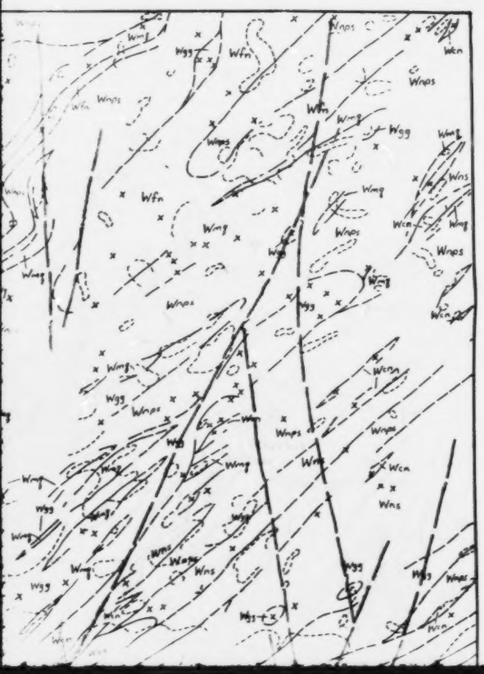
PETER LAKE AND ROTTENSTONE DOMAINS

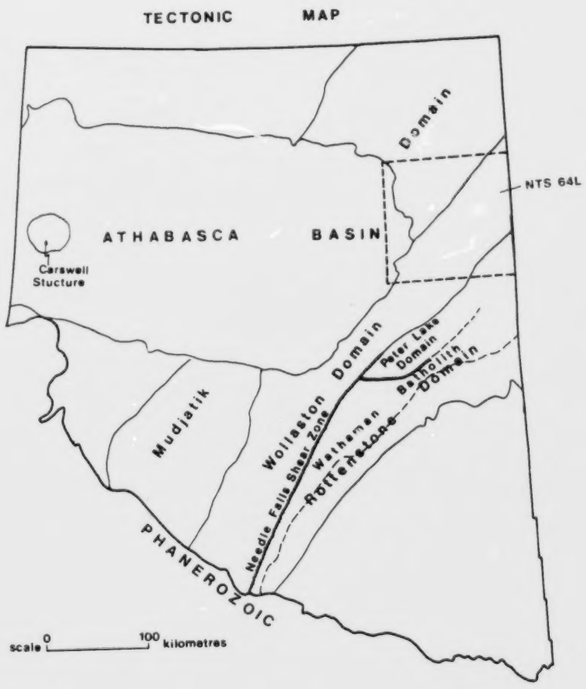
Rx — Mylonite: fine grained, laminated, generally siliceous, local feldspar augen present where derived from Unit Rgp

Rgl — Granite and granodiorite: fine to very coarse grained, massive to foliated, + biotite + hornblende + garnet, local supracrustal and/or metagabbro xenoliths, locally intruding Unit Rgp

Rgp — Megacrystic granitoids: medium to very coarse grained, massive to strongly foliated quartz monzonite, monzogranite and granodiorite, microcline megacrysts up to 20 cm across, + biotite + hornblende, local metapelitic and/or amphibolitic xenoliths;
similar in texture and appearance to parts of the







PROTEROZOIC

Wgg — *ionalite, granodiorite and monzogranite: ... to pegmatitic, locally megacrystic, + biotite + hornblende ± garnet, local pelitic and/or amphibolitic xenoliths;*
in part derived by anatexis of Wollaston Group supracrustal rocks, in part plutonic

Rgp — Megacrystic granitoids: medium to very coarse grained, massive to strongly foliated quartz monzonite, monzogranite and granodiorite, microcline megacrysts up to 20 cm across, + biotite + hornblende, local metapelitic and/or amphibolitic xenoliths;
similar in texture and appearance to parts of the Wathaman batholith (c. 1880 Ma) exposed south of the area
intruding unit Rgp

MAINLY EARLY TO MIDDLE APHEBIAN

WOLLASTON GROUP (and possible equivalents in Mudjatik Domain)

Hidden Bay Assemblage Type

Wq — Metaquartzite: fine to coarse grained, massive to well layered, + feldspar ± sillimanite ± muscovite ± biotite, local interlayered amphibolite;
correlation with quartzite near Charcoal Lake is uncertain

Wmq — Interlayered amphibolite, meta-arkose, metapsammopelite and calc-silicate rock: medium to coarse grained, massive to well foliated, quartz-poor amphibolite ± garnet ± diopside ± biotite, *probably of volcanic origin*; interlayered assemblage restricted to Rabbit Lake area, generally hornblende and/or diopside bearing, locally graphitic; layering ranges from a few metres to several hundred metres in thickness;
correlation with amphibolites near Charcoal Lake is uncertain

Wst — Pelitic gneiss and meta-arkosic gneiss: medium to coarse grained, commonly graphitic, biotite + quartz + feldspar gneiss interlayered with partly granitized, white, massive, biotite + sillimanite meta-arkose; strong EM conductor;
distribution outside Rabbit Lake area is uncertain

Wcn — Calc-silicate rock: generally coarsely recrystallized, variable texture, quartz-poor + actinolite/tremolite ± diopside ± albite ± carbonate ± epidote ± scapolite; occurring as conformable bands and lenses throughout the supracrustal sequence

Wns — Psammitic gneiss: fine to medium grained, massive to gneissic, locally layered, largely arkosic, + quartz + feldspar + biotite ± sillimanite ± garnet ± cordierite, local interlayered pelite, psammopelite, calc-silicate rock or sodic plagioclase-rich rock of possible evaporitic origin, commonly partially melted with granitic neosome comprising > 50 percent of the rock; in Hidden Bay area, upper part contains interlayered dolomitic marble

Wnsc : calcareous psammitic gneiss, + hornblende ± diopside ± actinolite/tremolite ± epidote

Wnsq : metaquartzite, ± sillimanite

Wn — Interlayered metapelite, metaquartzite, metapsammite and calc-silicate rock: lithological layers range from 1 m to 50 m thick, locally graphitic, locally partially melted, metaquartzite locally conglomeratic or brecciated;
unit considered equivalent to similar rocks of the Courtenay-Cairns Lake belt exposed south of the area

Wnps — Pelitic gneiss and psammopelitic gneiss: fine to coarse grained, foliated to gneissic, + biotite + quartz + feldspar ± graphite + garnet ± sillimanite ± cordierite ± sulphide, locally interlayered with metapsammite, calc-silicate rock or amphibolite, commonly partially melted with tonalitic neosome comprising > 50 percent of the rock

PROBABLY ARCHEAN

Wm — Amphibolite: medium to coarse grained, massive to well foliated, + hornblende + plagioclase ± biotite ± hypersthene; occuring as conformable bodies in Unit Wfn;
possible wide age range

Wfn — Granitoid rocks: medium to coarse grained, well foliated to gneissic, + biotite ± hornblende syenogranite to granodiorite, locally migmatitic with layers or inclusions of amphibolite and/or biotite schist;
probable basement to Aphebian supracrustal rocks ; in Mudjatik Domain, probably in part derived by anatexis of supracrustal rocks

Wfnh : hypersthene granitoid rocks, charnockite and enderbite, indicative of granulite facies metamorphic conditions

Rb — Metagabbro and metadiorite: medium to coarse grained, equigranular, massive to foliated, + hornblende + plagioclase; locally intruding Units Rf and Rm;
considered equivalent to Peter Lake Complex basic to intermediate intrusive rocks (c. 2540 Ma) exposed south of the area

Rbg : layered metagabbro, rhythmic layering, cumulate textures, minor ultramafic rock, anorthosite and granodiorite

Rm — Amphibolite: fine to medium grained, strongly foliated, locally banded, + hornblende + plagioclase + quartz, local interlayered granitic material;
probably mainly volcanic in origin

Rf — Banded quartzofeldspathic gneiss: fine to coarse grained, foliated, commonly colour banded, + biotite ± hornblende, local pelitic and/or amphibolitic layers;
probably mainly volcanic/pyroclastic in origin

Rfn — Foliated granitoid rocks: medium to coarse grained, strongly foliated to gneissic, + biotite + hornblende granite to granodiorite, local inclusions or layers of

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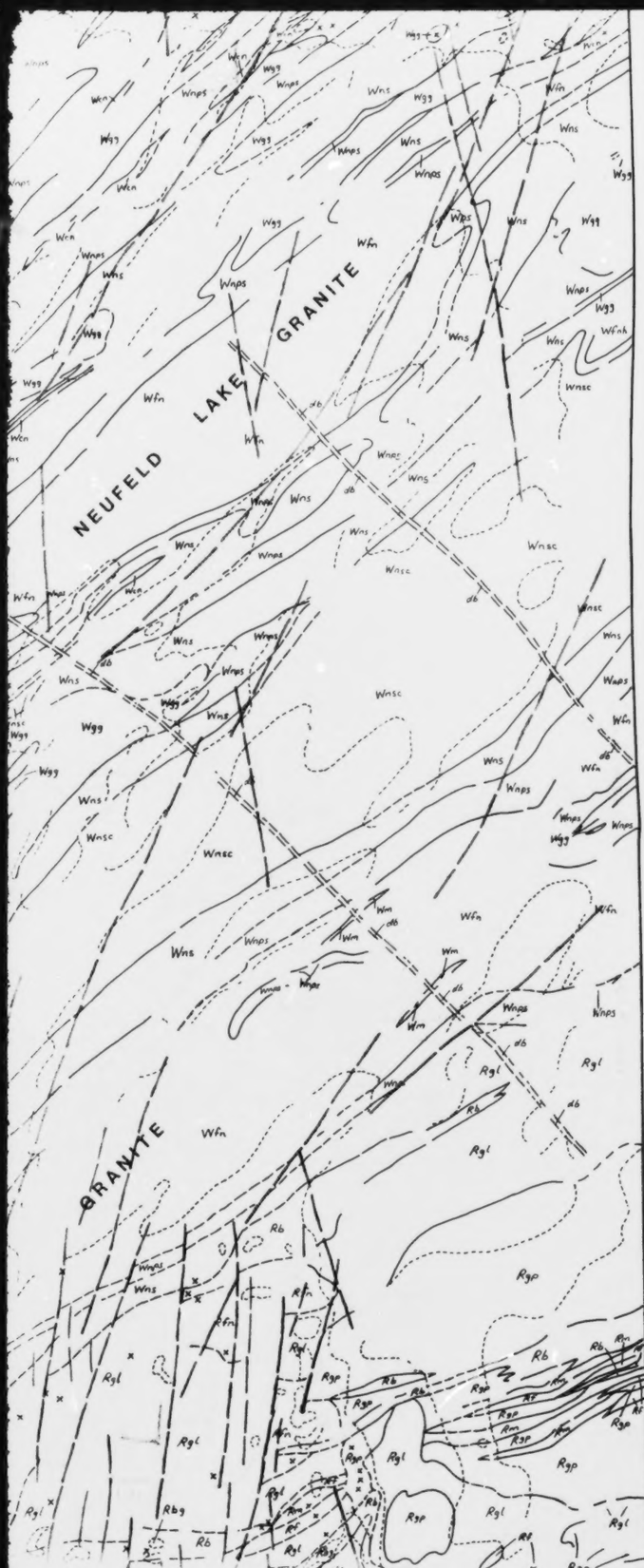
NEUFELD LAKE GRANITE
GRANITE
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Rf

PROBABLY ARCHEAN

Wm — Amphibolite: medium to coarse grained, massive to well foliated, + hornblende + plagioclase + biotite + hypersthene; occuring as conformable bodies in Unit Wfn;
possible wide age range

Wfn — Granitoid rocks: medium to coarse grained, well foliated to gneissic, + biotite + hornblende syenogranite to granodiorite, locally migmatitic with layers or inclusions of amphibolite and/or biotite schist;
probable basement to Aphebian supracrustal rocks ; in Mudjatik Domain, probably in part derived by anatexis of supracrustal rocks

Wfnh: hypersthene granitoid rocks, charnockite and enderbite, indicative of granulite facies metamorphic conditions

intermediate intrusive rocks (e.g. [illegible]) of the area

Rbg : layered metagabbro, rhythmic layering, cumulate textures, minor ultramafic rock, anorthosite and granodiorite

Rm — Amphibolite: fine to medium grained, strongly foliated, locally banded, + hornblende + plagioclase + quartz, local interlayered granitic material;
probably mainly volcanic in origin

Rf — Banded quartzofeldspathic gneiss: fine to coarse grained, foliated, commonly colour banded, + biotite + hornblende, local pelitic and/or amphibolitic layers;
probably mainly volcanic/pyroclastic in origin

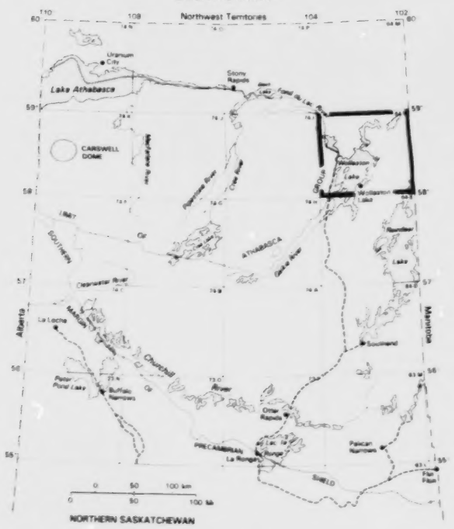
Rfn — Foliated granitoid rocks: medium to coarse grained, strongly foliated to gneissic, + biotite + hornblende granite to granodiorite, local inclusions or layers of amphibolite;
similar to presumed Archean basement granitoid rocks of Wollaston Domain

Geological compilation by M.W. Thomas, 1982.

Early draft compilations by B.P. Scott and R. Macdonald were consulted.

This map is provisional and is printed directly from the geologist's manuscript. It is issued with the "Summary of Investigations 1982, Saskatchewan Geological Survey" or separately, and is expected to be superseded by maps accompanying Saskatchewan Energy and Mines Report No. 211.

LOCATION MAP



Scale 1:250,000

Kilometres 6 0 6 12 18 Kilometres

Miles 4 0 4 8 12 Miles

Reference: Project 8207 Summary of Investigations 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 2-5.

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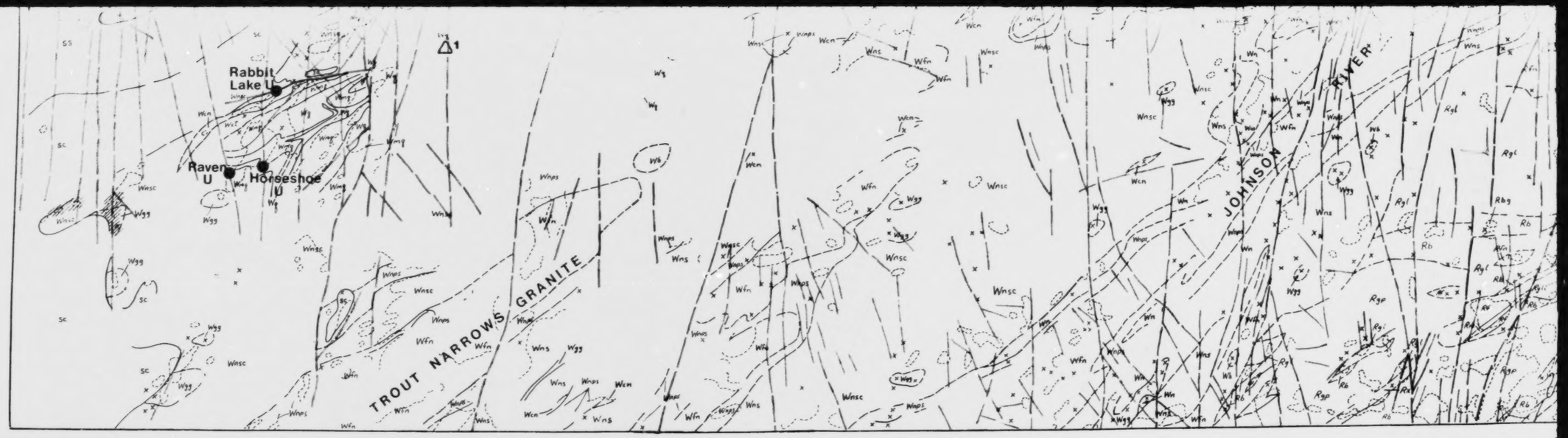
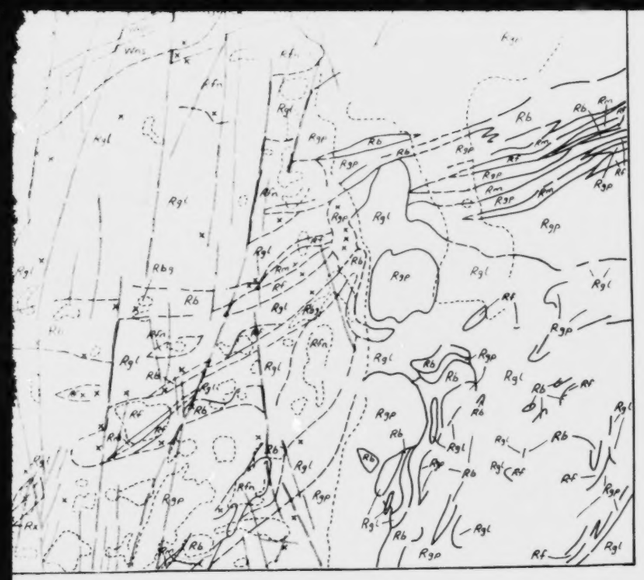


Base map reproduced directly from Federal Surveys and Mapping Branch 1:250,000 Series topographic map series, with acknowledgement.



Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Compilation Bedrock Geology: Reindeer Lake North Area (NTS 64E)

Preliminary Geological Map

by **M. W. THOMAS and ROBERT MACDONALD**

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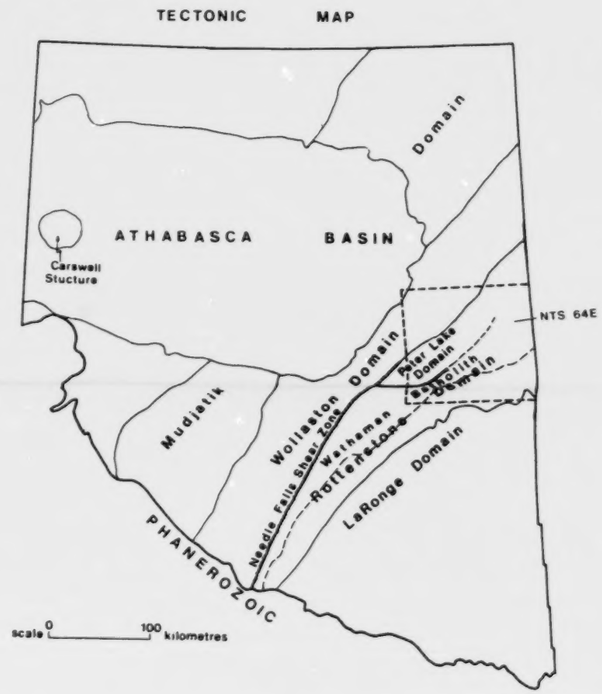
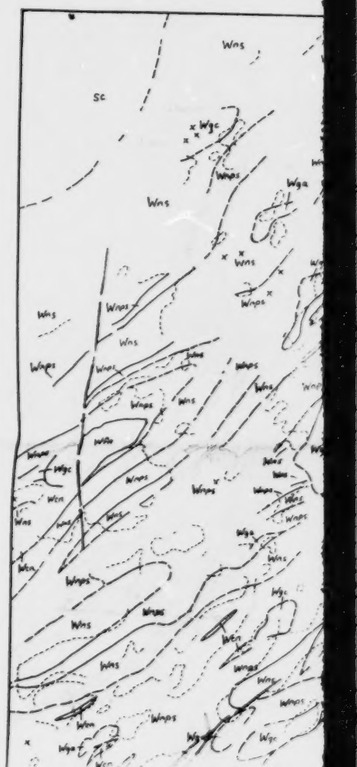




TROUT NARROWS GRANITE

LINN ISLAND GRANITE

HORTON ISLAND GRANITE

MIDDLE LAKE GRANITE

unmapped

ZENGLE LAKE GNEISS

McLEAN BAY GABBRO

unmapped

LEGEND

PALEOHELIKIAN

ATHABASCA GROUP

5C — Manitou Falls Formation: unmetamorphosed fluviatile quartz sandstone with 2 to 20 percent interstitial clay, locally interbedded with clast-supported conglomerates, overlying deeply weathered basement

WOLLASTON DOMAIN

LATE APHEBIAN (HUDSONIAN)

Wgc — Granitic pegmatite: variable grain size, generally massive, ± biotite ± muscovite ± garnet; contacts with migmatitic supracrustal gneisses commonly gradational

Wga — Granite and alaskite: fine to coarse grained, massive to weakly foliated, ± biotite ± hornblende ± magnetite ± microcline megacrysts; contacts with migmatitic supracrustal gneisss commonly gradational; Horton Island granite has strongly discordant intrusive contacts with country rocks

PETER LAKE AND ROTTENSTONE DOMAINS

PARKER LAKE GNEISSES

Rx — Mylonite: fine grained to aphanitic, streaky to finely laminated; with interlayered mafic and felsic gneiss

Rgn — Felsic gneiss: medium grained, strongly foliated to gneissic, locally laminated to submylonitic granitoid rock ± biotite ± hornblende ± augened microcline megacrysts;
probably largely derived from Unit Rgl

Rbn — Mafic gneiss: fine to medium grained, foliated to gneissic, locally laminated to submylonitic, + hornblende + plagioclase ± biotite + quartz ± potassium feldspar; local pods of weakly foliated to massive mafic rock;
probably largely derived from Unit Rb

Rgp — Megacrystic granitoids: medium to coarse grained, massive to foliated, with local igneous flow banding, + microcline megacrysts + biotite + hornblende quartz monzonite, monzogranite and granodiorite; local metapelite, amphibolite and/or metadiorite xenoliths; locally abundant pegmatite, aplite and non-megacrystic granitoid towards margins of some bodies

Rgpx: Sheared variants, with strongly foliated groundmass and flasered microcline megacrysts, locally submylonitic

Rbd — Quartz monzodiorite, diorite and gabbro: fine to coarse grained, massive to foliated, + hornblende + plagioclase ± potassium feldspar ± quartz ± biotite, with local paragneiss inclusions; contact zones commonly injected with granitic material;
compositionally similar and possibly in part equivalent to Unit Rb

Rgc — Granitic pegmatite: massive to foliated, ± biotite ± muscovite ± hornblende ± garnet

Rgt — Tonalite, granodiorite and trondhjemite: compositionally variable, generally potassium feldspar-poor, fine to coarse grained, locally pegmatitic, massive to foliated, + biotite ± muscovite + garnet + hornblende + amphibolite, with local metapelite inclusions;
considered to have undergone multistage intrusion,

LA RONGE DOMAIN

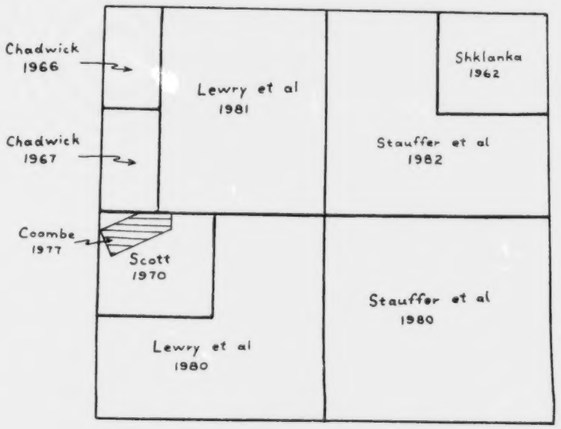
Lgd — Granodiorite and quartz monzonite: medium grained, well foliated to gneissic, biotite + hornblende; with abundant xenoliths of paragneiss and Unit Lgtq

Lgtq — Quartz monzodiorite: fine to coarse grained, foliated to gneissic, + hornblende + biotite; with abundant xenoliths of paragneiss and amphibolite; neosomes of granodioritic to quartz monzonitic material in migmatitic contact zone

PROTEROZOIC

scale 0 100 kilometres

COMPILATION SOURCES



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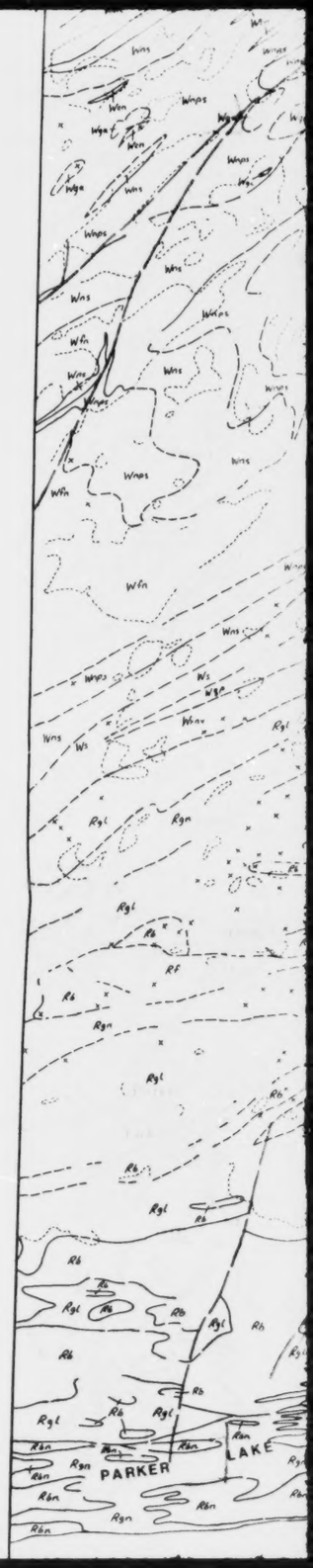


unmapped

JOHNSON RIVER GRANITE

ETTLE CREEK GRANITE

BATHOLITH

GEORGE LAKE Zn,Pb

BROWN PROSPECT Zn,Pb,Cu

REILLY LAKE SHEAR ZONE

LAKE SHEAR ZONE

PROTEROZOIC

considered to have undergone multistage intrusion, anatexis and migmatization

Rgtz: metasomatized leucotonalite, pink, massive, porphyroblastic, with introduced potassium feldspar and quartz in aureole of Wathaman batholith

Rmg — Amphibolite and derived migmatite: *paleosome* fine to medium grained, foliated, locally layered, + hornblende + feldspar + biotite ± muscovite ± garnet + quartz; with local pelitic to psammitic gneiss and calc-silicate gneiss; *neosome* tonalitic, granodioritic or trondhjemitic (50 to 90 percent of unit), medium to coarse grained to pegmatitic, massive to foliated, + biotite ± muscovite ± garnet ± hornblende

Rng — Pelitic to psammitic gneiss and derived migmatite: *paleosome* fine to medium grained, well foliated to gneissic, locally layered, + biotite + quartz + feldspar + muscovite ± garnet + sillimanite ± graphite; *neosome* tonalitic, granodioritic or trondhjemitic (50 to 90 percent of unit), medium to coarse grained to pegmatitic, massive to foliated, + biotite ± muscovite ± garnet ± hornblende

ROTTENSTONE TONALITE-MIGMATITE COMPLEX

Rgl — Granite and granodiorite: medium to coarse grained, massive to strongly foliated to gneissic, locally submylonitic, local relict igneous textures, + biotite ± hornblende; with local amphibolite and/or metapelite inclusions; intrudes Unit Rb;
possibly in part derived by anatexis of supracrustal rocks, including possible Archean elements

PETER LAKE COMPLEX

EARLY TO MIDDLE APHEBIAN

WOLLASTON GROUP

Wcn — Calc-silicate gneiss, marble and amphibolite: medium grained to pegmatitic, variable composition and texture, + diopside ± albite ± hornblende ± biotite ± actinolite/tremolite ± calcite ± scapolite ± grossularite ± wollastonite; occurring as conformable bands and lenses in supracrustal sequence

Wns — Meta-arkosic gneiss: fine to medium grained, massive to foliated to gneissic, locally compositionally layered, ± biotite ± hornblende ± diopside ± muscovite ± sillimanite ± garnet ± cordierite ± magnetite ± pyrite; locally interlayered with metaquartzite, metapelite and calc-silicate rock; commonly partially melted with leucogranitic neosome (> 50 percent of rock)

Wnps — Pelitic to psammopelitic gneiss: fine to medium grained, foliated to gneissic, + biotite + quartz + feldspar + graphite + sillimanite + muscovite ± cordierite ± garnet ± pyrite/pyrrhotite; interlayered metaquartzite, meta-arkose, calc-silicate rock and marble, with psammitic types locally abundant; commonly partially melted with leucogranitic to tonalitic neosome (> 50 percent of rock) especially in north-central part of area

Ws — Mixed metasediments: variable unit both along and across strike, generally fine grained and foliated; interlayered laminated slate, meta-argillite, metaquartzite, metachert, meta-arkose, calc-silicate rock, marble and rare banded iron formation;
possible facies equivalent to Unit Wnps

Wqp — Metaquartzite: fine grained, massive to foliated, locally compositionally layered, + muscovite ± biotite ± garnet ± feldspar ± hornblende ± sulphide; local conglomerate, interlayered graphitic meta-argillite ± andalusite ± garnet ± sulphide;
unit equivalent to upper part of Souter Lake group (Scott, 1970)

COURTENAY-CAIRNS LAKE BELT

EARLY APHEBIAN

Wrnv — Meta-arkose with minor amphibolite: fine to medium grained, massive to foliated, locally layered and cross stratified, ± muscovite ± magnetite ± lithic fragments; local conglomerate with granite, granite gneiss and metavolcanic and/or metasedimentary clasts; local interbedded pelitic schist ± andalusite ± staurolite ± garnet; intercalated fine grained massive to poorly foliated amphibolites, locally pillowed;
equivalent to Courtenay Lake group and lower part of Souter Lake group (Scott, 1970)

Rb — Metagabbro and metadiorite: fine to coarse grained, massive to foliated, local relict ophitic, subophitic texture, + hornblende + plagioclase + biotite + actinolite/tremolite; with local metasedimentary xenoliths; appears to intrude Unit Rsl;
includes amphibolitic rocks of possible metavolcanic origin

Rbg: layered metagabbro, minor anorthosite, ultramafic rock and granodiorite

Wfn — Granitoids: fine to coarse grained, massive to foliated to gneissic syenogranite to granodiorite, + biotite ± amphibole ± sillimanite, with rare hypersthene (indicating local granulite facies metamorphism); local

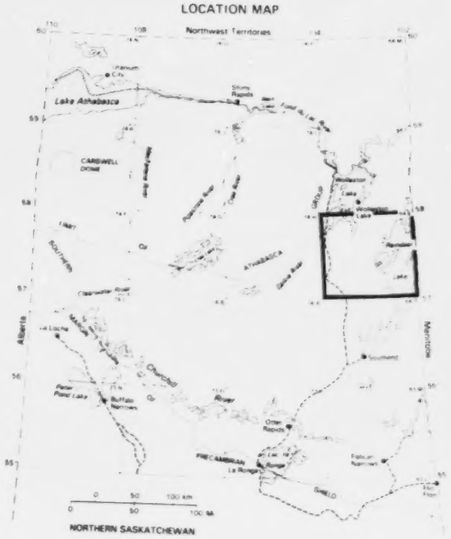
Slimmon, W.L., Coleman, L.C., Bussom, L. and Langford, F.F. (1981): Geology of the Gallentin Island vicinity, Wollaston Lake; Sask. Mineral. Resour., Rep. 206.

Geological compilation by Robert Macdonald and M.W. Thomas, 1980 and 1982.

Early draft compilation with assistance of Robert George.

This map is provisional and is printed directly from the geologists' manuscript. It is issued with the "Summary of Investigations 1982, Saskatchewan Geological Survey" or separately, and is expected to be superseded by maps accompanying Saskatchewan Energy and Mines Report No. 232

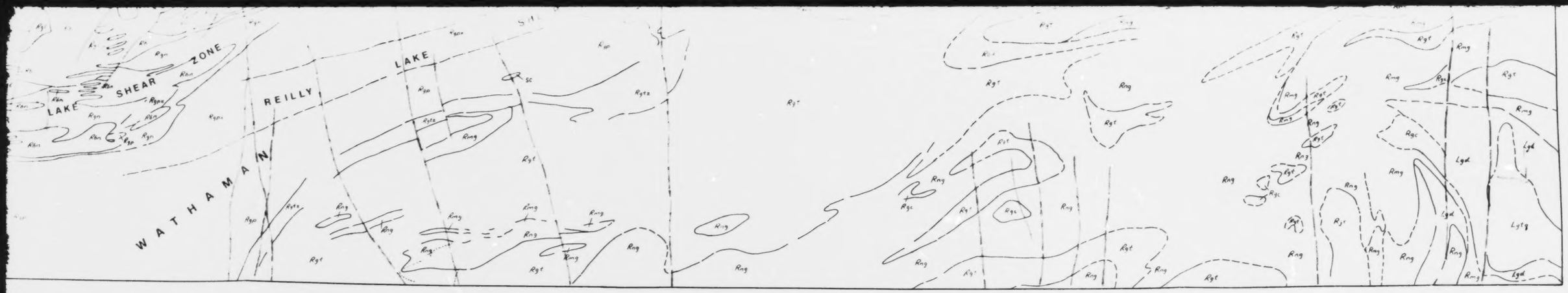
LOCATION MAP



NORTHERN SASKATCHEWAN

Scale 1:250,000

Reference: Project 8201 Summary of Investigations 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 6, 7.



Interim corrections 1974
Corrections provisoires, 1974

ROADS - ROUTES

hard surface - Dur		
loose surface - Ordinaire		
cart track - Sentier		
trail - sentier		
Deletions - Suppressions		x x x x x

Road, all weather	Chemin toute saison	
Road, fair weather	Chemin de terre, beau temps	
Trail or portage	Sentier ou portage	
Town	Ville	□
Village or settlement	Village ou hameau	○
Post office	Bureau de poste	P
Building	Bâtiment	•

Boundary, undefined	Limite imprécise	
Contour interval feet	Equidistance des courbes en pieds	25'0"
Railway	Chemin de fer	
Marsh or swamp	Marais ou marécage	
Depression contours	Courbes de cuvette	
Surveyed line	Ligne arpentée	

TRE
GRID

PROBABLY ARCHEAN

Wmv — Meta-arkose with minor amphibolite: fine to medium grained, massive to foliated, locally layered and cross stratified, + muscovite + magnetite + lithic fragments; local conglomerate with granite, granite gneiss and metavolcanic and/or metasedimentary clasts; local interbedded pelitic schist + andalusite + staurolite + garnet; intercalated fine grained massive to poorly foliated amphibolites, locally pillowed;
equivalent to Courtenay Lake group and lower part of Souter Lake group (Scott, 1970)

Wfn — Granitoids: fine to coarse grained, massive to foliated to gneissic syenogranite to granodiorite, + biotite ± amphibole ± sillimanite, with rare hypersthene (indicating local granulite facies metamorphism); local amphibolite and/or pelitic schist inclusions; locally partially melted with massive leucogranite neosome;
probable basement to Aphebian supracrustal rocks

PETER LAKE COMPLEX

Rb — Metagabbro and metadiorite: fine to coarse grained, massive to foliated, local relict ophitic, subophitic texture, + hornblende + plagioclase ± biotite ± actinolite/tremolite; with local metasedimentary xenoliths; appears to intrude Unit Rsl;
includes amphibolitic rocks of possible metavolcanic origin

Rbg: layered metagabbro, minor anorthosite, ultramafic rock and granodiorite

CAMPBELL RIVER GROUP

Rsl — Slate, phyllite and biotite schist: very fine to fine grained, well foliated, locally layered, + biotite + muscovite + pyrite/pyrrhotite ± carbonaceous material; with local hornblende-biotite schist, metapsammite, amphibolite and metagabbro

Rf — Quartzofeldspathic gneiss: fine to medium grained, equigranular, generally well foliated to gneissic, locally compositionally banded, granitic to granodioritic in composition, + biotite + hornblende; with local biotite-hornblende gneiss lenses;
probably of supracrustal origin in part

SYMBOLS

Geological boundary; approximate, inferred

Structural lineament, possible fault, as interpreted from geological, geophysical and/or airphoto evidence

Mineral prospect

Bedrock exposure

Area of abundant bedrock exposure

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Geology of the Sub-Athabasca Basement, Cree Lake Area (NTS 74G)

Preliminary Geological Map

by **C. F. GILBOY**

FEB 15 1983

Legend:

PRECAMBRIAN

INTRUSIVE

D — Diabase; dark grey to dark green, medium to coarse grained, massive, subophitic

G — Granite; generally pale to moderate pink, medium-grained, massive to weakly foliated, homogeneous, containing about 5 percent biotite

METASEDIMENTARY *(mainly Aphebian, M where undifferentiated)*

Mq — Quartzite; white to pale grey, medium to coarse grained, well foliated to massive, containing up to 5 percent kaolinized feldspar, and rare muscovite and/or sillimanite

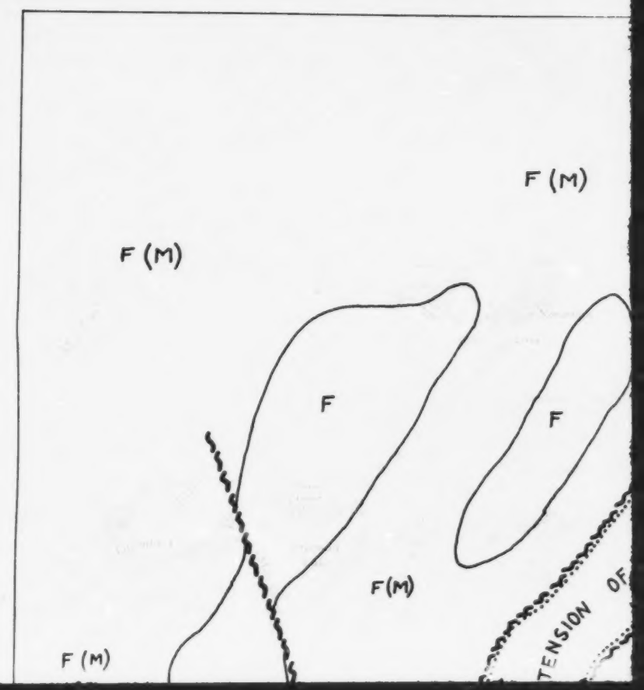
Mp — Biotite gneiss, semipelitic to pelitic; moderate grey, medium grained, well foliated, containing more than 10 percent biotite, garnet, sillimanite and/or cordierite (or their alteration products)

Mpg — Biotite gneiss, graphitic, semipelitic to pelitic; moderate to dark grey, medium grained, well foliated, generally containing traces to 3 percent graphite and more than 7 percent biotite, garnet, sillimanite and/or cordierite (or their alteration products)

ROCKS OF UNKNOWN ORIGIN

A — Amphibolitic gneiss; moderate to dark grey or green, fine to coarse grained, schistose to massive, containing 35 to 70 percent amphibole ± biotite

F — Felsic gneiss; pale pink or grey, medium to [illegible]



F (M)

F

TENSION OF VIRGIN RIVER SHEAR ZONE
(MIXED MYLONITES)

D?

D?

F,G ?

F,G ?

D?

M (F)

??

ROCKS OF UNKNOWN ORIGIN

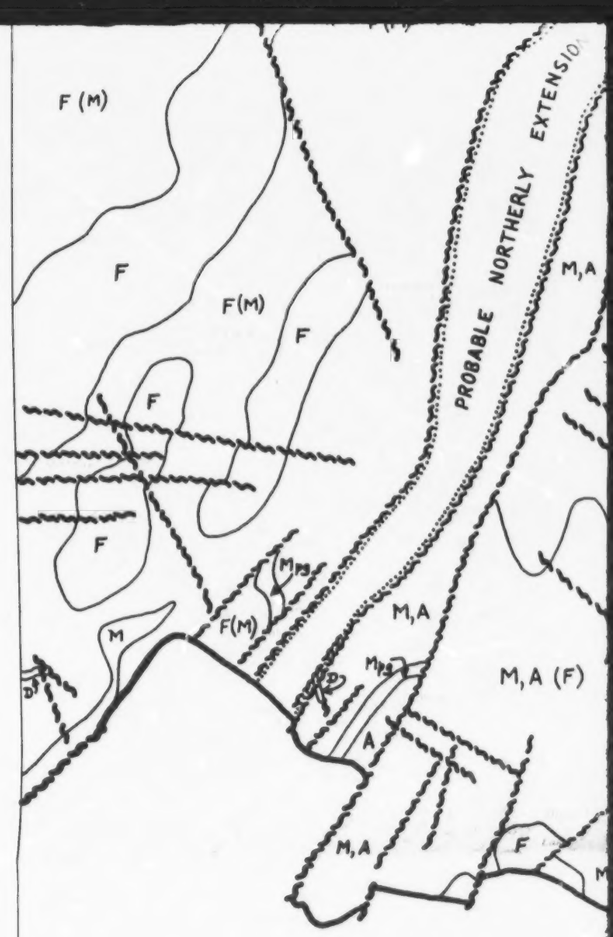
A	Amphibolitic gneiss; moderate to dark grey or green, fine to coarse grained, schistose to massive, containing 35 to 70 percent amphibole ± biotite
F	Felsic gneiss; pale pink or grey, medium to coarse grained, well foliated; generally containing 5 to 10 percent biotite ± amphibole; *mainly of probable Archean age*

SYMBOLS

- Edge of Athabasca Group
- Geological boundary, approximate
- Fault or fracture, inferred
- Domain boundary, approximate

Map reliability decreases from south to north with increasing thickness of Athabasca Group cover, fewer exploratory holes and less well-defined interpretation of geophysical data.

Geology and compilation by C.F. Gilboy with assistance from D.G. MacDougall and J.A. MacEachern.



PROBABLE NORTHERLY EXTEN

F,M?

M,A

F,G ?

M,A

M,A (F)

F

M?

F,G

D

D

D

Mpg

D

D

Mpg

G

Mpg

F

F

Mp,
Mpg

Mpg,P

F

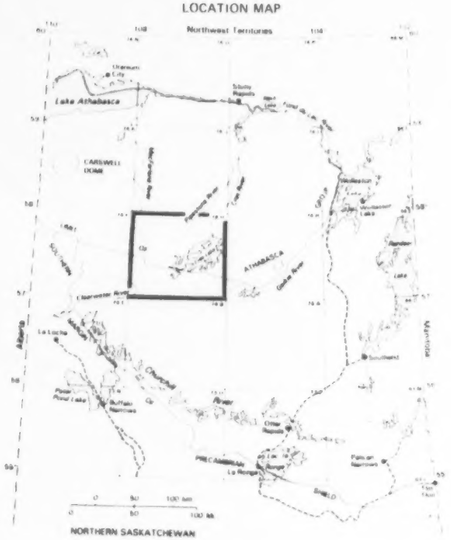
M(F)

F

F

F

LOCATION MAP



Geology and compilation by C.F. Gilboy, 1981, 1982 with assistance from D.G. MacDougall and James MacEachern.

This map is provisional and is printed directly from the geologist's manuscript. It is issued with the "Summary of Investigations 1982, Saskatchewan Geological Survey" or separately.

Scale 1:250,000

Kilometres 6 0 6 12 18 Kilometres

Miles 4 0 4 8 12 Miles

Reference: Project 8206 Summary of Investigations, 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 12-25.

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IFICATION

640

RES

7

5
75

4

4
44

TEN THOUSAND METRE GRID

Winter ice road	Chemin de terre ou d'hiver
Trail or portage	Sentier ou portage
River	Rivière
Village or settlement	Village ou hameau
Post office	Bureau de poste
Building	Bâtiment

PROVISIONAL MAP

The nomenclature on this map has not been submitted to the Canadian Board on Geographical Names and may be subject to revision.

Horizontal control point	Point geodésique
Boundary monument	Borne frontière
Spot elevation, in feet	Repère de nivellement en pieds 2550
Rapids, falls	Rapides, chutes
Marsh or swamp	Marais ou marécage
Depression contours	Courbes de cuvette
Surveyed line	Ligne arpentée

(4)

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Geology of the Sub-Athabasca Basement, Geikie River Area (NTS 74H)

Preliminary Geological Map

by **C. F. GILBOY**

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Legend:

PRECAMBRIAN

INTRUSIVE

D — Diabase; dark grey to dark green, medium to coarse grained, massive, subophitic

P — Pegmatite; pink or white, variably grained, massive, containing biotite ± muscovite ± tourmaline

G — Granite; generally pale to moderate pink, medium grained, massive or weakly foliated, homogeneous, containing about 5 percent biotite

METASEDIMENTARY *(Mainly Aphebian,* M *where undifferentiated)*

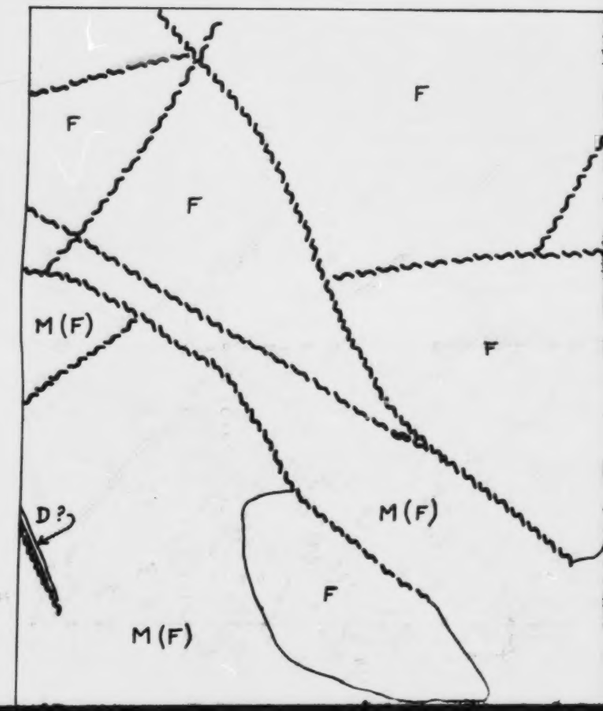
Mn — Meta-arkose; pale to moderate pink, grey or green, fine grained, weakly foliated, generally containing less than 5 percent mafic minerals

Mc — Calc-silicate rock and marble; calc-silicate rock generally dark green serpentinous and veined by dolomite; marble is a fine- to coarse-grained equigranular rock containing tremolite, phlogopite, epidote and/or spinel

Mq — Quartzite; white to pale grey, medium to coarse grained, well foliated to massive, containing up to 5 percent kaolinized feldspar, and rare muscovite and/or sillimanite

Mp — Biotite gneiss, semipelitic to pelitic; moderate grey, medium grained, well foliated, containing more than 10 percent biotite, garnet, sillimanite and/or cordierite (or their alteration products)

Mpg — Graphitic biotite gneiss, semipelitic to pelitic; moderate to dark grey, medium grained, well foliated,



F

M (F)

M (F)

F ?

Mp,q

Mm,p

Mm

Mm,G

Mm

Mm,G

Mm

Mm,G

Mm

Mm,G

Mm

Mm

Mm

Mp — Biotite gneiss, semipelitic to pelitic; moderate grey, medium grained, well foliated, containing more than 10 percent biotite, garnet, sillimanite and/or cordierite (or their alteration products)

Mpg — Graphitic biotite gneiss, semipelitic to pelitic; moderate to dark grey, medium grained, well foliated, generally containing traces to 3 percent graphite and more than 7 percent biotite, garnet, sillimanite and/or cordierite (or their alteration products)

ROCKS OF UNKNOWN ORIGIN

A — Amphibolitic gneiss; moderate to dark grey or green, fine to coarse grained, schistose to massive, containing 35 to 70 percent amphibole ± biotite

F — Felsic gneiss; pale pink or grey, medium to coarse-grained, well foliated; generally containing 5 to 10 percent biotite ± amphibole; *probably mainly of Archean age*.
Fa; dark to moderate pink variety, compositionally and texturally homogeneous, possibly of intrusive origin;
Fb; pale to moderate pink, texturally and compositionally inhomogeneous;
Fc; pale grey to white, texturally and compositionally inhomogeneous with much pegmatitic segregation material

SYMBOLS

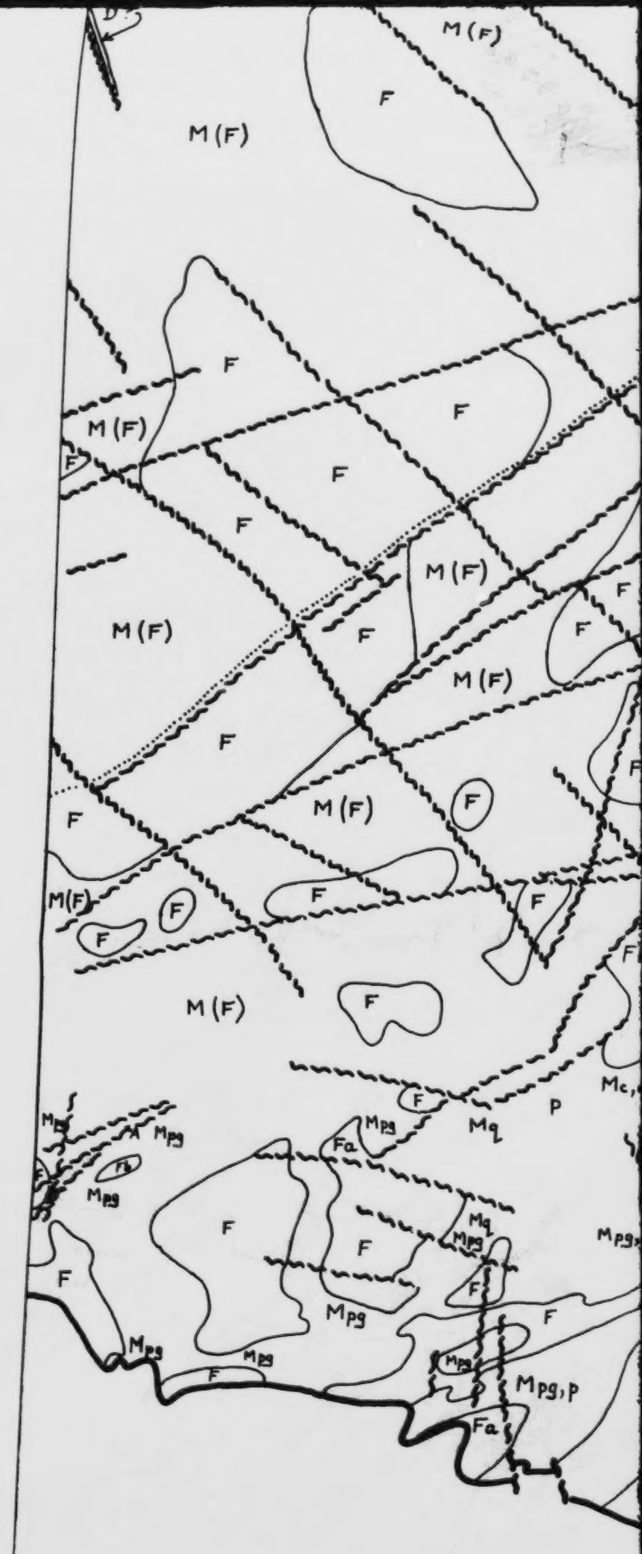
Edge of Athabasca group

Geological boundary, approximate

Fault or fracture, inferred

Domain boundary, approximate

Map reliability decreases from southeast to northwest with increasing thickness of the Athabasca Group cover, fewer exploratory holes, and less well-defined interpretation of geophysical data



M (F)
Mp,q
Mm,p
Mm ?
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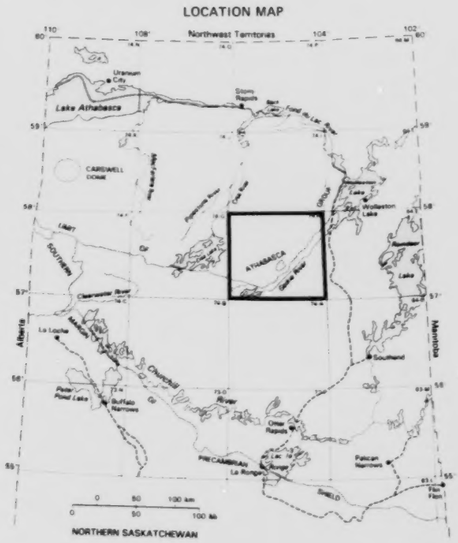
Mp
Mm
Mm
Mm,G
G
G
Mp
Mm
Mm
Mp
Mp
F
F
Fc
Mp
F
M(F)
F
Mp
F
Mq
Fc
Mq
Mpg
F
Mm ?
Mm ?
Mp,pg
Mm
Mpg
Mp
Mm,A
Fa
Fa,c
F
D
OUTCROP
M
Mm,p
Fb
Mm
Mp
Mm
D
Mm,p
Mpg
Fa
Mm
D
Mc,q
Mpg,P
Mm
Mp
Mm
Mpg,P
Mpg
F
Mm
Mm,p
Mpg,P
F

Base map reproduced directly from Federal Surveys and Mapping Branch 1:250,000 Series topographic map series, with acknowledgment.

LOCATION MAP



Geology and compilation by C.F. Gilboy, 1981, 1982 with assistance from D.G. MacDougall and James MacEachern.

This map is provisional and is printed directly from the geologist's manuscript. It is issued with the "Summary of Investigations 1982, Saskatchewan Geological Survey" or separately.

Scale 1:250,000

Kilometres 6 0 6 12 18 Kilometres

Miles 4 0 4 8 12 Miles

Reference: Project 8206 Summary of Investigations, 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 12-25.

Mm

F

Mm

Mm,p

Mpg,p

F

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Geology of an Area around Mickey Lake (NTS 74N)

Preliminary Geological Map

by **D. J. THOMAS**

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Legend:

PRECAMBRIAN

8 PALEOHELIKIAN

Beaverlodge Formation, Martin Group, talus breccia, cobble conglomerate, minor arkosic beds

———————— UNCONFORMITY ————————

HUDSONIAN

Late syn-to post-tectonic

7 Intrusive leucogranite and alaskite, massive to weakly foliated

Pre-to early syn-tectonic

6 "Granitic" quartzofeldspathic gneisses, largely metasomatic, in part intrusive; 6a, gneissic and foliated **granite, 6b, mylonitic quartzofeldspathic gneiss; 6c, brecciated granitoid**

5 Donaldson Lake gneiss, heterogeneous granitic gneisses comprising intrusive and possibly "older" basement elements

———— INTRUSIVE-METASOMATIC CONTACT (in part) ————

APHEBIAN (?)

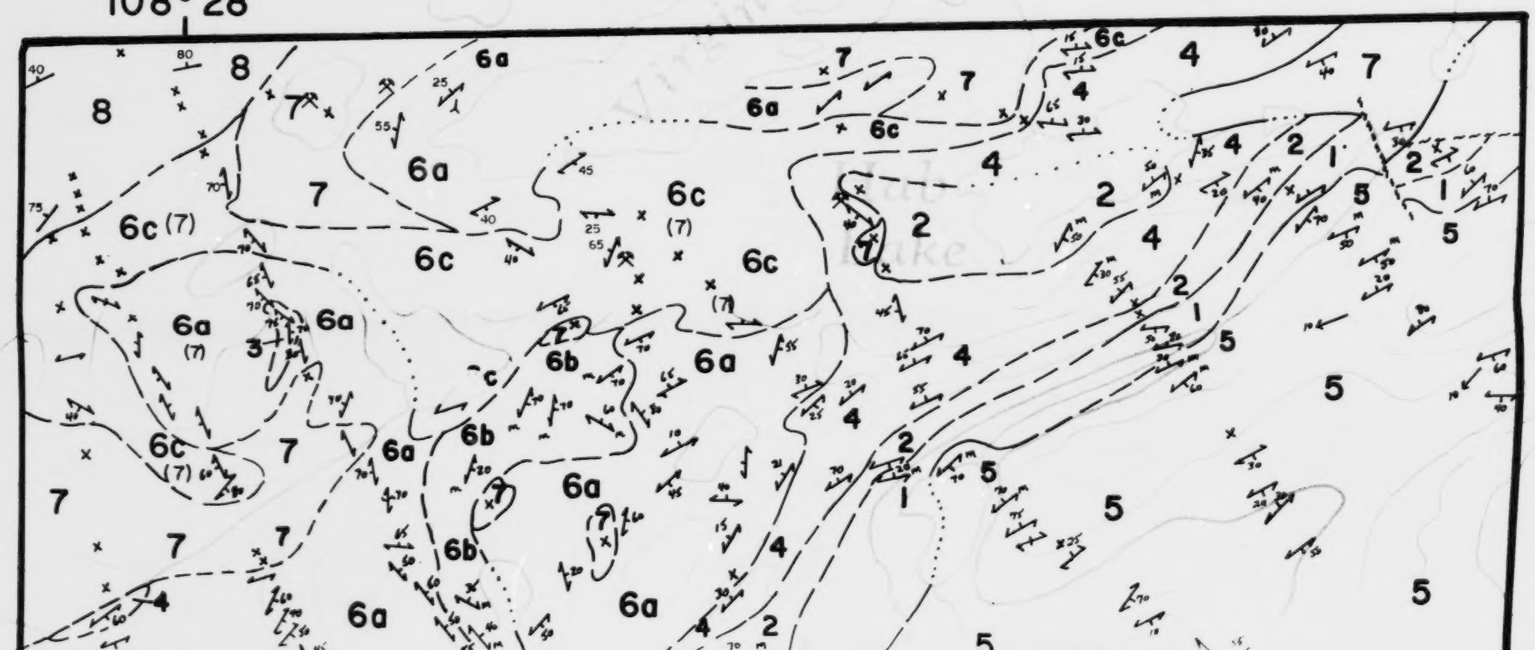
Fay Mine Complex

4 Argillite-slate, minor quartzite, mica (chlorite) schist and massive epidote-chlorite rock

3 Hornblende schist-amphibolite, minor argillite, and "dirty" grey quartzite

2 Quartzite, minor mica schist, hornblende schist argillite

108°28'


8
7
6a
6c (7)
6c
6b
6a (7)
6c (7)
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6b
6a
6a
6c
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2
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5

4	Argillite-slate, minor quartzite, mica (chlorite) schist and massive epidote-chlorite rock
3	Hornblende schist-amphibolite, minor argillite, and "dirty" grey quartzite
2	Quartzite, minor mica schist, hornblende schist argillite and red granite
1	Mica schist - quartzite, biotite (chlorite)-sercite-quartz schist, sercite-quartz schist, grey quartzite

SYMBOLS

Lithological boundary: defined, gradational approximate

Fault

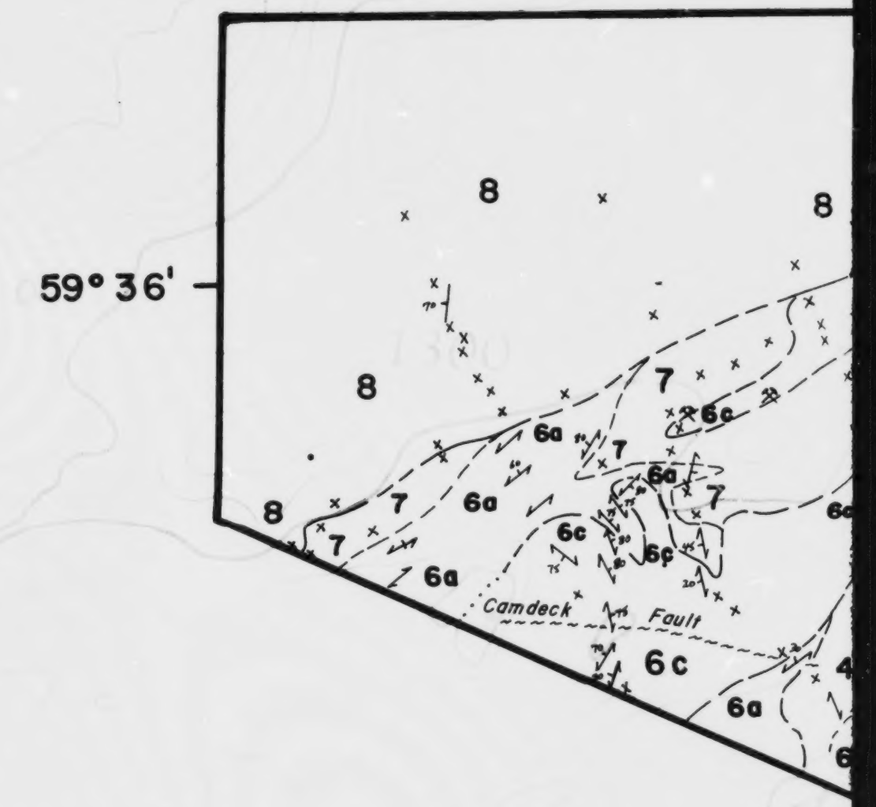
Bedding strike and dip: inclined, vertical

Foliation, gneissosity, schistosity strike and dip: inclined, vertical

Mineral lineation and rodding: plunge and trend

Mapped outcrop: no structure

Uranium mineralization: trenched area



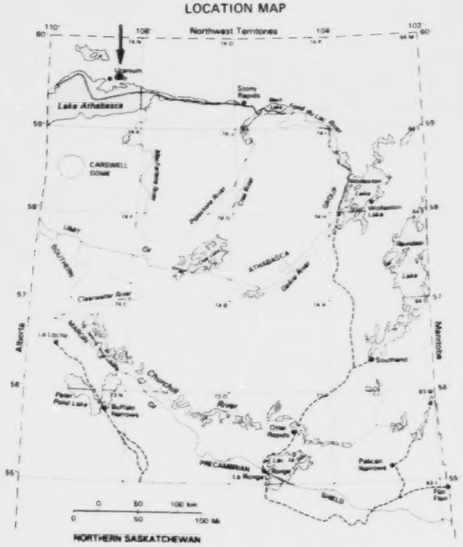
59° 36'
108° 28'
Mic Mic Fault
Tom Fault
Long Lake
Mic Lake
Camp

Robinson
Island
Foot
Bay

Geologically mapped by D.J. Thomas, 1982.

This map is provisional and is printed directly from the geologist's manuscript. It is issued with the "Summary of Investigations 1982, Saskatchewan Geological Survey" or separately.

LOCATION MAP

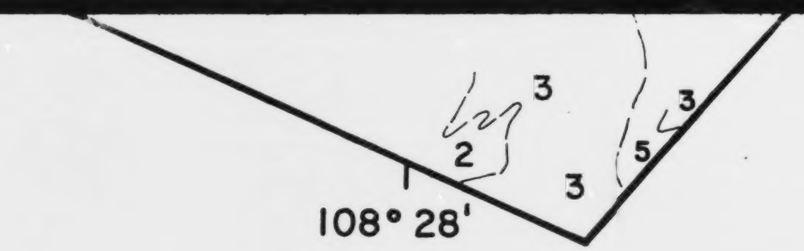


Scale 1:10,000

Metres 500 0 500 Metres

Feet 500 0 500 1000 1500 2000 2500 Feet

Reference: Project 8212 Summary of Investigations 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 51-55.


3
2
3
5
3
108° 28'

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Geology of the Robinson Creek Gold Occurrence (NTS 63L)

Preliminary Geological Map

by **J. G. PEARSON**

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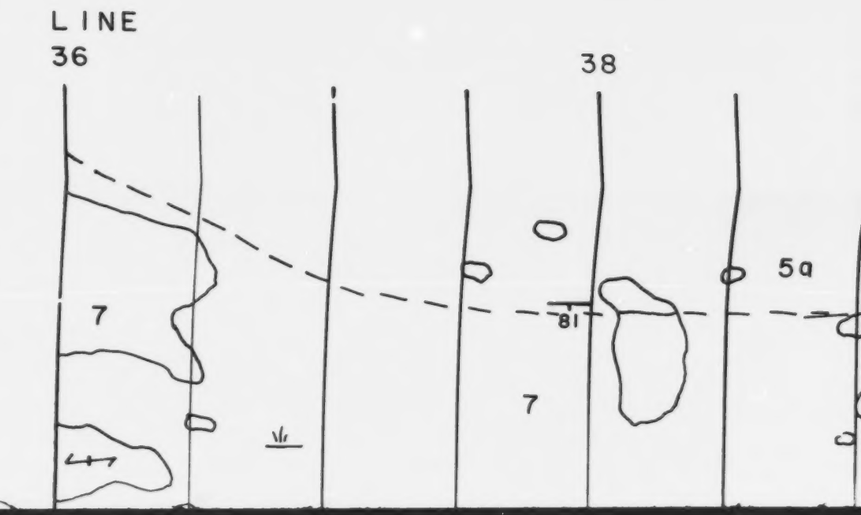

ccurrence

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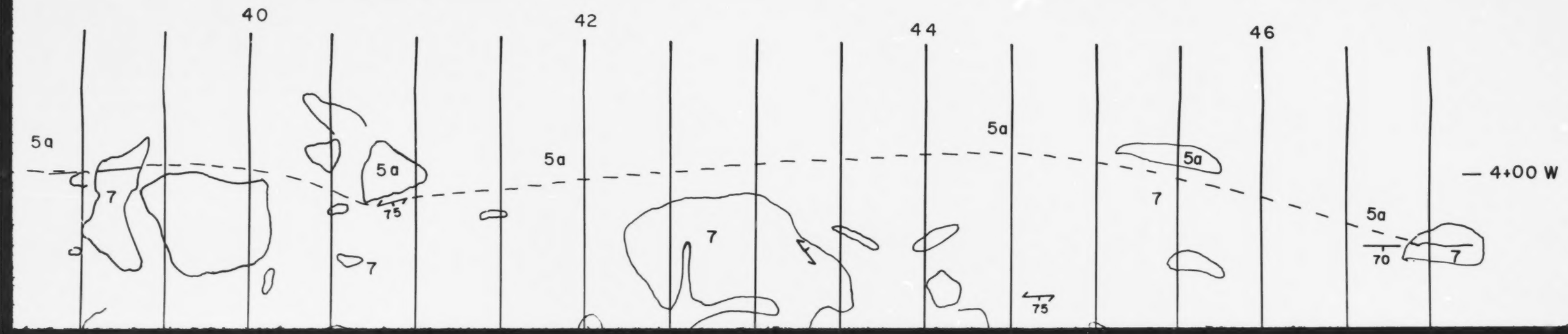
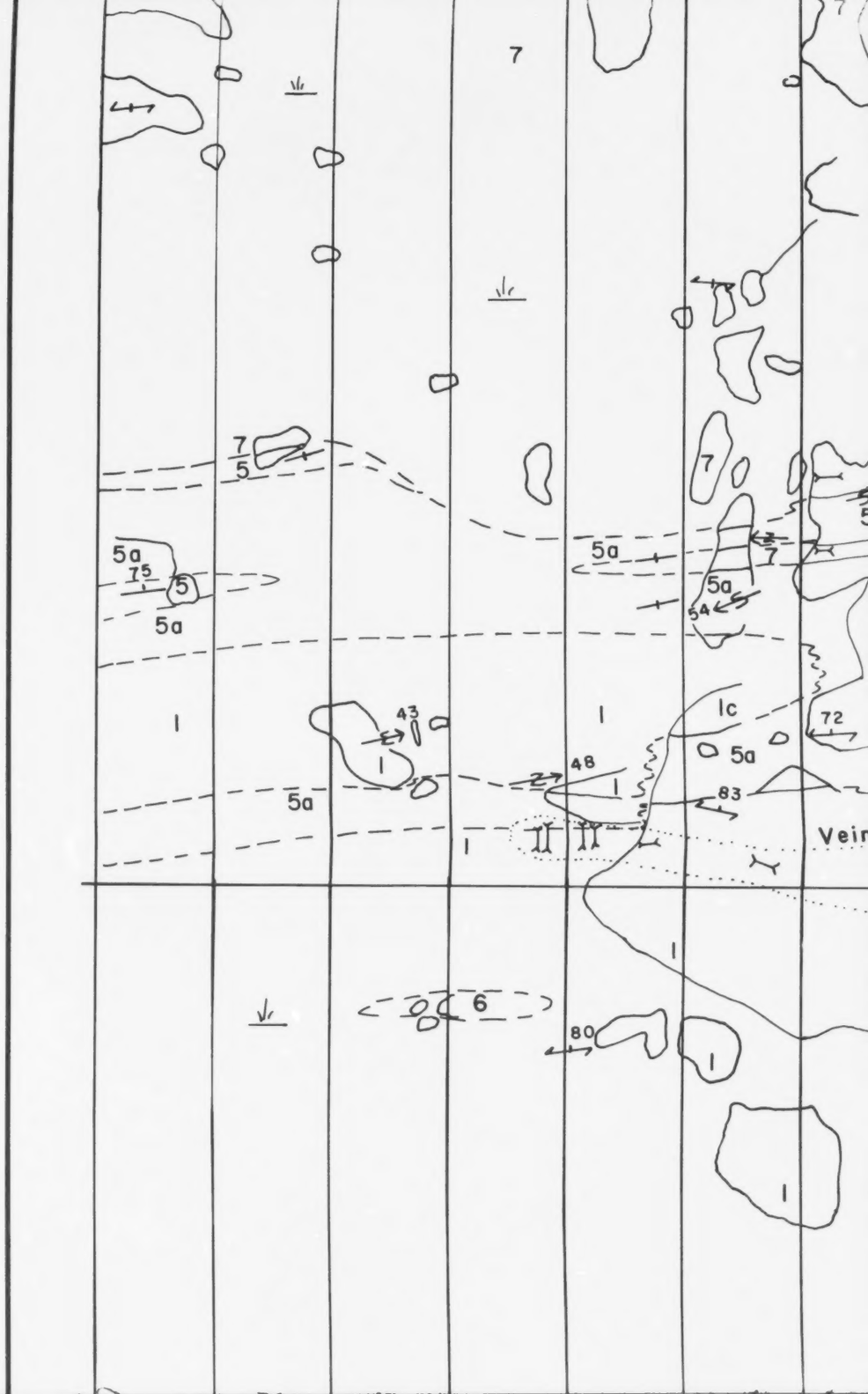



7
7
5
5a
7
5
5a
5a
5a

— 3+00 W

— 2+00 W

— 1+00 W

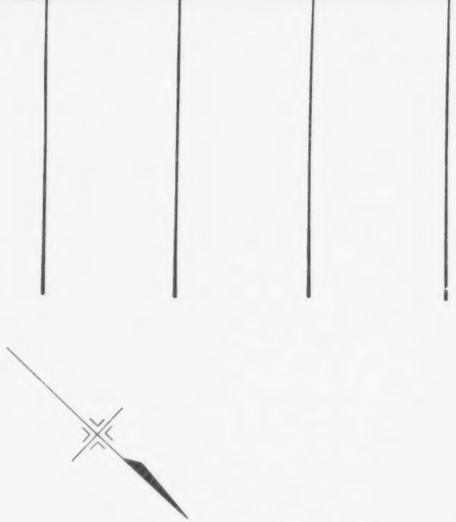
— BASE LINE

— 1+00 E

— 2+00 E

Quartz Zone

Bleiler Zone



Geology by J.G. Pearson, 1982.

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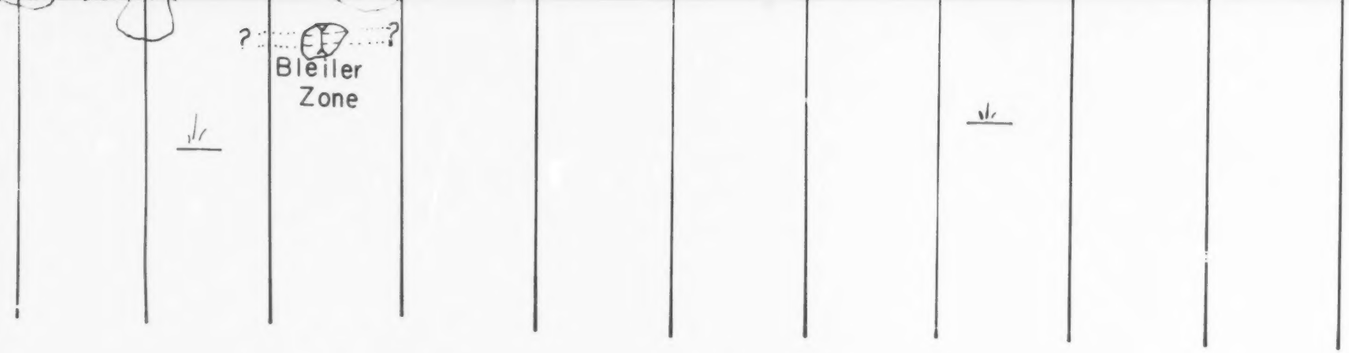
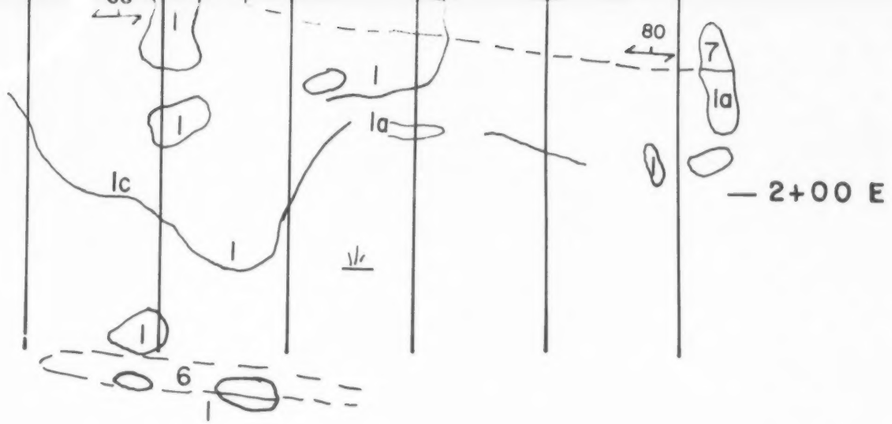
Scale

0 100 200 300 400 500 ft

Reference: Project 8214 Summary of Investigations 1982, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 82-4, p. 64-70.





Survey,

LEGEND

POST MISSI INTRUSIVE ROCKS

7 Reynard Lake Pluton: porphyritic granodiorite

6 Gabbro

MISSI GROUP

5a Conglomerate

5 Greywacke

UNCONFORMITY

AMISK GROUP

1 Basalt: 1a, massive flows; 1b, breccia; 1c, fragmental

SYMBOLS

Bedding strike and dip: inclined, vertical

Foliation strike and dip: inclined, vertical

Fold axis plunge; trend and fold style

Outcrop, area of outcrop

Muskeg

Geological boundary; defined, assumed

Zone of gold mineralization and/or alteration

Trench

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Geology of the Dianne Lake Prospect Area (NTS 74N)

Preliminary Geological Map

by **B. P. SCOTT**

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Legend:

5 Diabase

4 Granite; pink, hornblendic, slightly foliated

3 Mylonite; local sheared felsic gneiss

2 Felsic gneiss-migmatite: pink, granitic/arkosic matrix, locally with inclusions of hornblende gneiss, sheared and recrystallized, in part mylonite

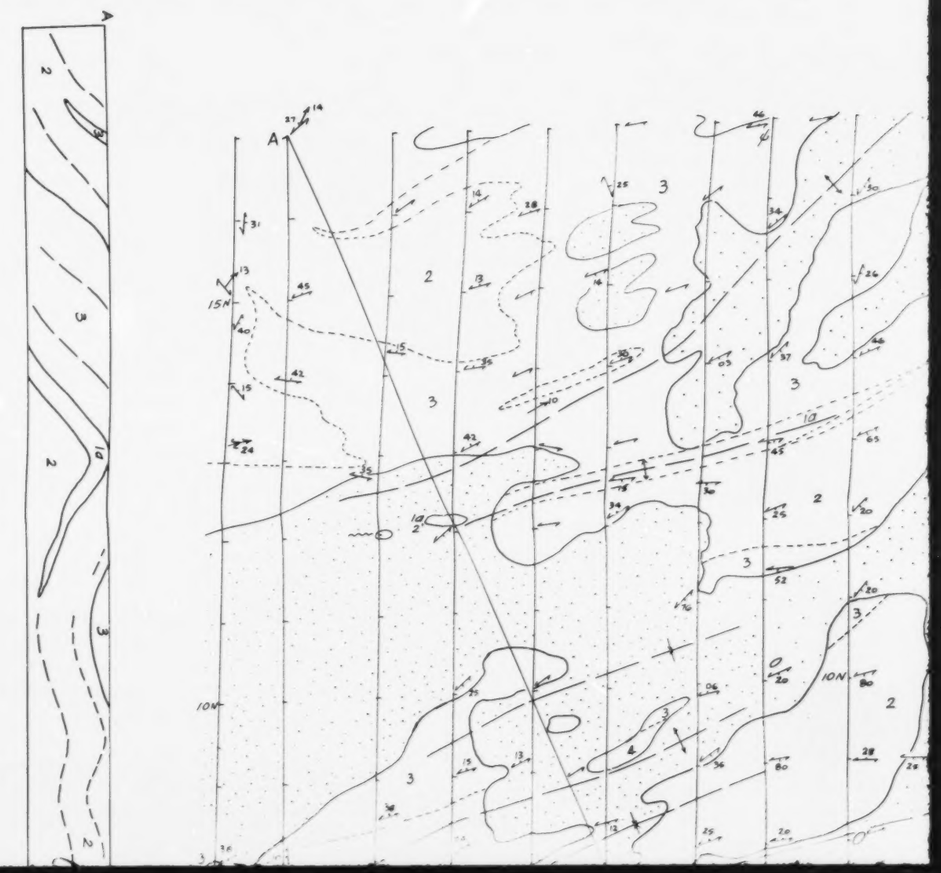
1 Biotite migmatite; grey, medium- to coarse-grained, felsic neosome, biotite-hornblende and cordierite-sillimanite-garnet-pyrite-bearing paleosome, minor

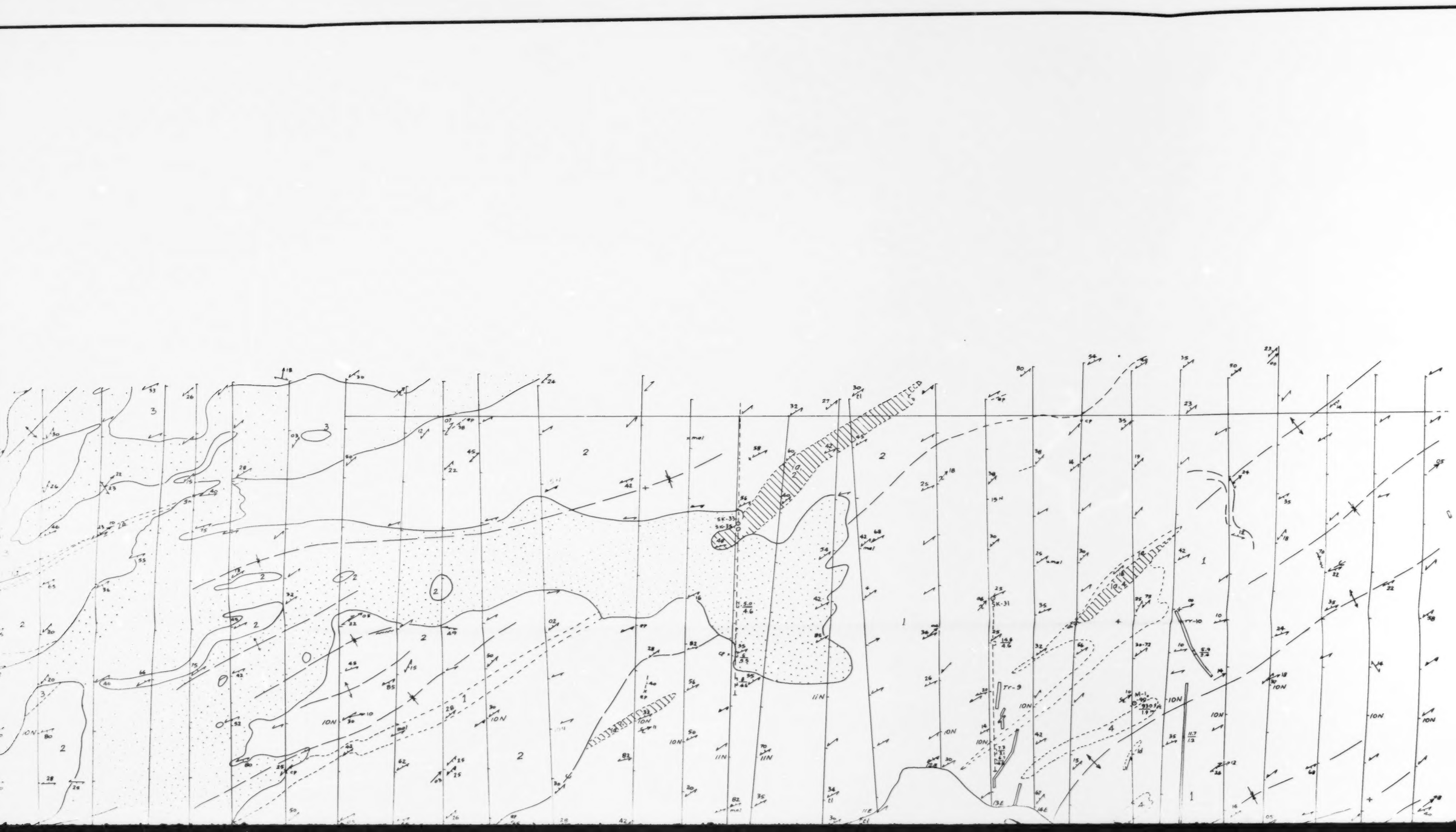
- 1a, amphibolite, hornblende gneiss
- 1b, quartzite
- 1c, feldspathic quartzite
- 1d, diopsidic rock

SYMBOLS

Geological boundary

15 Foliation strike and dip: inclined, vertical





Geological boundary

Foliation strike and dip: inclined, vertical

Younger foliation strike and dip: inclined, vertical

Axial plane of small-scale fold strike and dip: inclined, vertical

Axis of small-scale fold: plunge trend and fold style

Lineation of minerals and rodded inclusions: plunge and trend

Major axis of small-scale dome/basin

Antiform axial trace

Synform axial trace

Joint; inclined

Trend lines of foliation

Fault

Small scale fault

Small outcrop

Boulder

Glacial striae

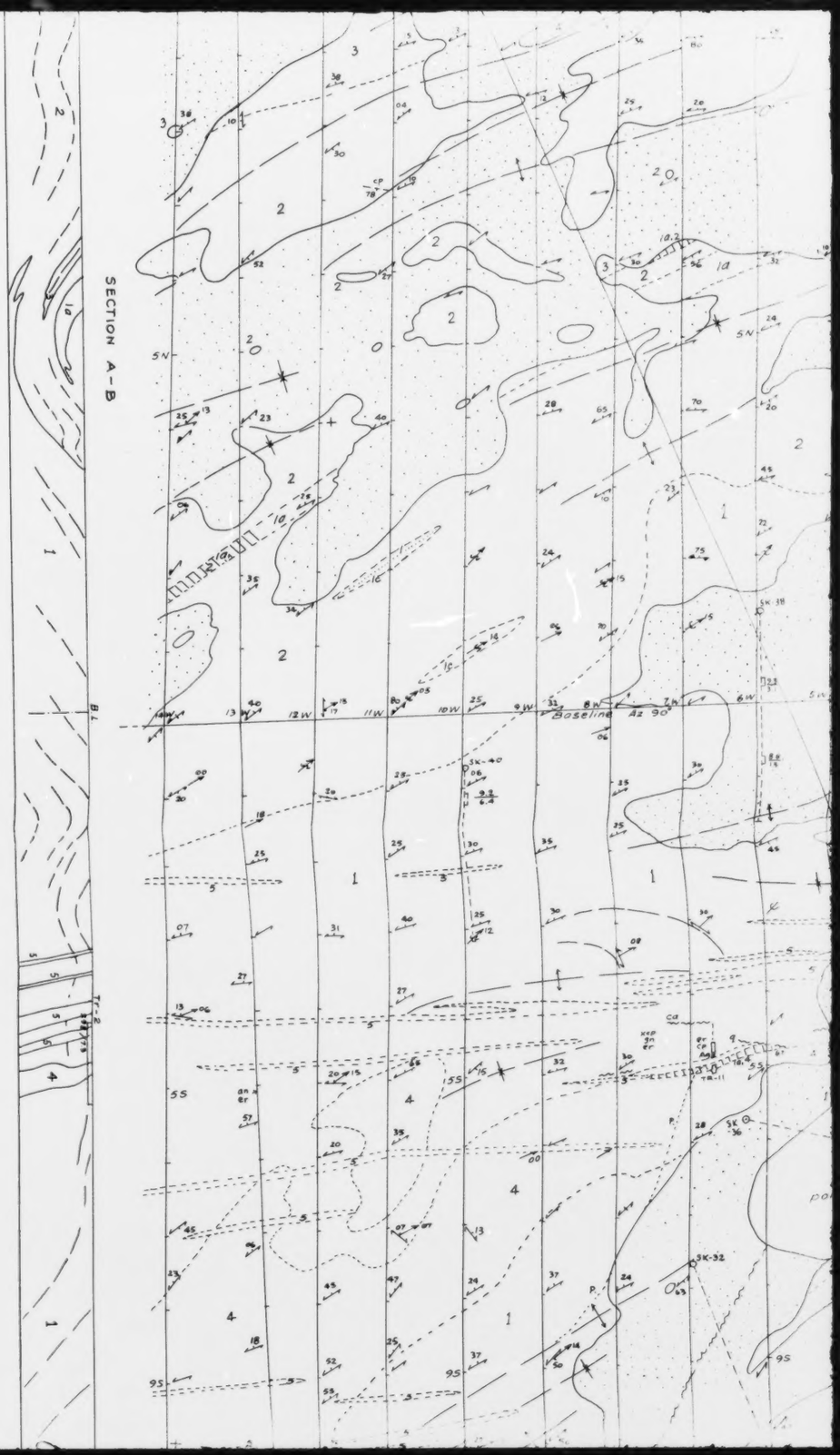
Overburden

Portage

Trench

Diamond drill hole: intersection, grams Ag/tonne ÷ metres

X bo	bornite	X ep	epidote
X cp	chalcopyrite	X q	quartz
X ni	niccolite	X ct	cordierite
X ma	malachite	X sil	sillimanite
X az	azurite	X ca	calcite
X er	erythrite (Cobalt bloom)	X gn	galena
X Ag	silver	X ra	rammelsbergite
X an	annabergite (Nickel bloom)		

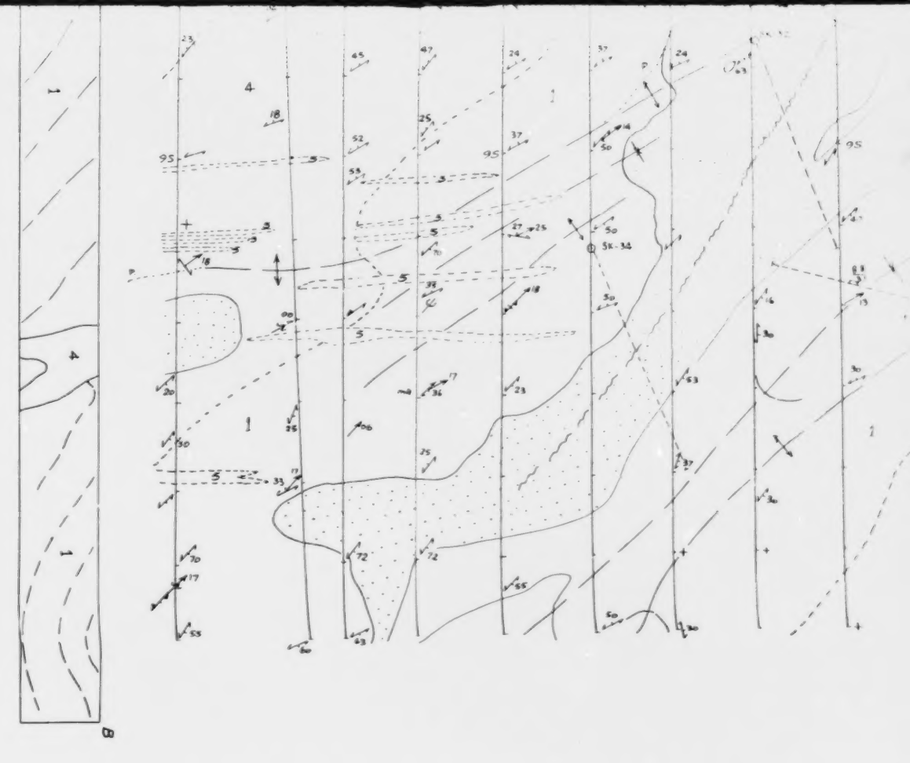


Doug L

Dianne L

pond

X er	erythrite (Cobalt bloom)	X gn	galena
X Ag	silver	X ra	rammelsbergite
X an	annabergite (Nickel bloom)		



Geological mapping and compilation by
B.P. Scott, 1982.

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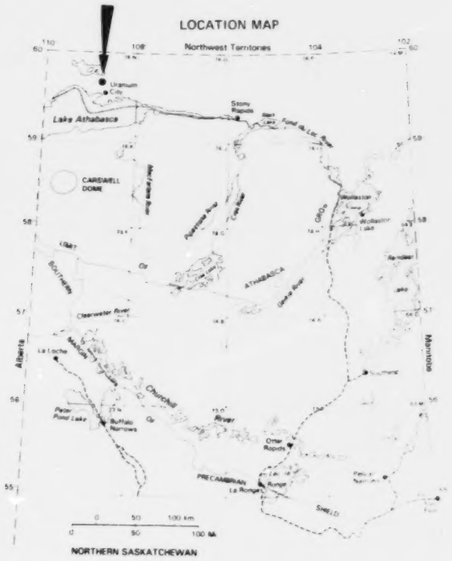

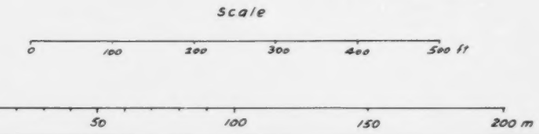

Reference: Project 8210 Summary of Investigations 1982, Saskatchewan Geological Survey, Sask. Energy and Mines, Misc. Rep. 82-4, p. 71-72.

A
B
C
D
Sk 41
Sk 42
Sk 43
Sk 44
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8 E
9 E
10 E
11
12
13 E
14 E
18 E
19 E
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21 E
22 E